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**FAA Technical Center**
Atlantic City International Airport
N.J. 08405

# Study of Bird Ingestions into Small Inlet Area Aircraft Turbine Engines
## (May 1987-April 1989)

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December 1990

FINAL REPORT

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16. Abstract

This report summarizes 2 years of data collection on ingestion of birds into small inlet area aircraft turbine engines. A total of 16.1 million engine operations were flown by aircraft equipped with the small inlet area engines (ALF502, TFE731, TPE331, and JT15D) included in the study. This includes 24 months of operations for the first three engines and 12 months of operations for the fourth. A total of 210 engine ingestion events were reported during the 2 years of data collection. This report analyzes these events to determine probability of ingestion, probability of degree of damage, probability of ingestion by phase of flight, and frequency of ingestion by geographic area.

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TABLE OF CONTENTS


| SECTION | | PAGE |
|---|---|---|
| EXECUTIVE SUMMARY | | vii |
| 1 | INTRODUCTION | 1 |
| | 1.1 Background | 1 |
| | 1.2 Objectives | 1 |
| | 1.3 Organization of Report | 2 |
| 2 | ENGINE OPERATIONS | 3 |
| 3 | CHARACTERISTICS OF INGESTED BIRDS | 10 |
| 4 | INGESTION RATES | 21 |
| | 4.1 Ingestion Rate Estimates | 21 |
| | 4.2 The Poisson Process | 24 |
| | 4.3 Validity of the Poisson Process Model for Bird Ingestion | 25 |
| | 4.4 Inlet Throat Area Effect on Ingestion Rates | 26 |
| | 4.5 Inlet Throat Diameter Effect on Ingestion Rates | 27 |
| 5 | ENGINE DAMAGE DESCRIPTION | 28 |
| | 5.1 Engine Damage Description | 28 |
| | 5.2 Probability of Damage | 36 |
| | 5.3 Crew Action Description | 40 |
| | 5.4 Engine Failure | 40 |
| 6 | PROBABILITY ESTIMATES | 46 |
| 7 | DATA QUALITY | 51 |
| | 7.1 Data Sources | 51 |
| | 7.2 Internal Consistency | 51 |
| 8 | CONCLUSIONS | 56 |
| 9 | REFERENCES | 58 |
| 10 | GLOSSARY OF TERMS | 59 |

APPENDICES

A - Engine Applications

B - Contents of FAA Small Inlet Area Turbine Engine Bird Ingestion Database

C - Statistical Methods Used


A-1

## LIST OF ILLUSTRATIONS


| FIGURE | | PAGE |
|---|---|---|
| E-1 | Small Inlet Area Turbine Engine Bird Ingestion Study Data Summary | viii |
| 2.1 | Operations, ALF502 Engine | 7 |
| 2.2 | Operations, TFE731 Engine | 8 |
| 2.3 | Operations, TPE331 Engine | 9 |
| 3.1 | Distribution of Bird Weights | 13 |
| 3.2 | Aircraft Ingestions by Month for 2 Years | 16 |
| 3.3 | Ingestions by Time of Day | 19 |
| 3.4 | Multiple Bird Ingestions by Time of Day | 19 |
| 3.5 | Multiple Engine Ingestions by Time of Day | 19 |
| 3.6 | Contour Map of Domestic Aircraft Ingestion Events | 20 |
| 4.1 | Comparison of Actual and Theoretical Cumulative Distributions | 26 |
| 5.1 | Severity of Damage for Turbofan Engines Versus Bird Weight Range | 38 |
| 5.2 | Probability of Any Damage versus Bird Weight | 41 |
| 5.3 | Probability of At Least Moderate Damage versus Bird Weight | 41 |
| 5.4 | Probability of Severe Damage versus Bird Weight | 42 |
| 7.1 | Comparison of Bird Weight Distributions, First and Second Years | 55 |

## LIST OF TABLES


| TABLE | | PAGE |
|---|---|---|
| 2.1 | Hours and Operations - ALF502 | 4 |
| 2.2 | Hours and Operations - TFE731 | 5 |
| 2.3 | Hours and Operations - TPE331 | 6 |
| 3.1 | Tally of Positively Identified Bird Species | 11 |
| 3.2 | Distribution of Bird Weights | 12 |
| 3.3 | Summary Statistics for Ingested Bird Weights | 14 |
| 4.1 | Engine Ingestion Rates | 22 |
| 4.2 | Engine Ingestion Events and Rates by Phase of Flight | 23 |
| 5.1 | Definition of Engine Damage Categories | 29 |
| 5.2 | Turbofan Engine Damage Caused by Bird Ingestions | 30 |
| 5.3 | Tally of Positively Identified Bird Species by Bird Weight Range and Engine Type | 32 |
| 5.4 | Bird Ingestion Turbofan Damage Summary | 33 |
| 5.5 | Bird Ingestion Turboprop Damage Summary | 34 |
| 5.6 | Phase-Of-Flight (POF) Analysis | 35 |
| 5.7 | Aircraft Airspeed Analysis | 35 |
| 5.8 | Multiple Engine and Multiple Bird Analysis | 37 |
| 5.9 | Conditional Probability of Crew Action and In-flight Shutdown Given the Engine Damage Severity | 43 |
| 5.10 | Engine Failure Summary by Bird Weight | 44 |
| 6.1 | Engine Ingestion Probabilities | 47 |
| 6.2 | Probability of an Engine Ingestion Event Versus Bird Weight | 48 |
| 6.3 | Probabilities of an Engine Ingestion Event | 49 |
| 6.4 | Engine Ingestion Probabilities | 50 |
| 7.1 | Comparison of Ingestion Rates for First and Second Years | 52 |
| 7.2 | Cumulative Distributions, First and Second Years | 54 |

## EXECUTIVE SUMMARY

An investigation was intitiated by the Federal Aviation Administration (FAA) Technical Center in May 1987 to determine the numbers, weight, and species of birds which are ingested into small inlet area turbofan and turboprop engines during worldwide service operation and to determine what damage, if any, results. Small inlet area engines are defined as those engines having an inlet area up to approximately 1400 square inches. This report presents an analysis of the 2 years of data. The purpose of the analysis is to assist the FAA in evaluating certification test requirements for such engines. In particular, this report presents information concerning ingestion events as related to time of day, phase of flight, month, location and bird species and weight.

Figure E-1 is an overall summary of the data that were collected during the 2-year period from May 1, 1987, to April 30, 1989. Throughout the world during that time there were approximately 16 million operations by the engines included in the data (ALF502, TFE731, TPE331 and JT15D). This figure includes 24 months of operations for the first three engines and 12 months of operation for the fourth. A total of 210 engine ingestion events were reported during this period. The probability of an engine ingestion event occurring is $1.3 \times 10^{-5}$ per operation. Thus, the ingestion of a bird is a rare but not impossible occurrence.

Within the United States, the most frequently ingested bird weight is 4 ounces, while outside the United States, the most frequently ingested bird weight is 7.7 ounces. However, birds in the range of 0 to 4 ounces actually outnumber the birds in the range of 4 to 8 ounces. Within the United States, half the ingested birds weigh over 4 ounces, while *outside the* United States, the median weight is 7.7 ounces. Bird weights are based on identification of bird species.

Most bird ingestions occurred in the Northern Hemisphere. Several tests were made to detect seasonal patterns in these data. However, if seasonality exists, these tests as described in Section 3 were not able to detect it.

It was found that ingestions occurred more frequently in the daytime than at night. More than likely this is the result of two factors: fewer aircraft flights at night and more birds flying in the daytime.

No geographic patterns seem to be apparent in the bird ingestions in the United States. The Northeast and Midwest States seem to form a block of states with several ingestions, but no single state in that area had more than five (Ohio, second highest number in the nation). The largest number of ingestions (11) in one state occurred in California. This may be explained by a conjunction of many seabirds and a high level of aircraft activity.

It was determined that the engine ingestions could be described adequately by a Poisson distribution. This made it possible to test hypotheses about the relationship between engine size and ingestion rate. The data are consistent with the hypothesis that ingestion rates are directly related to engine cross section area. It was determined that the ingestion experience of the turboprop engine was different from that of the turbofan engines, but the reasons for this difference could not be determined.

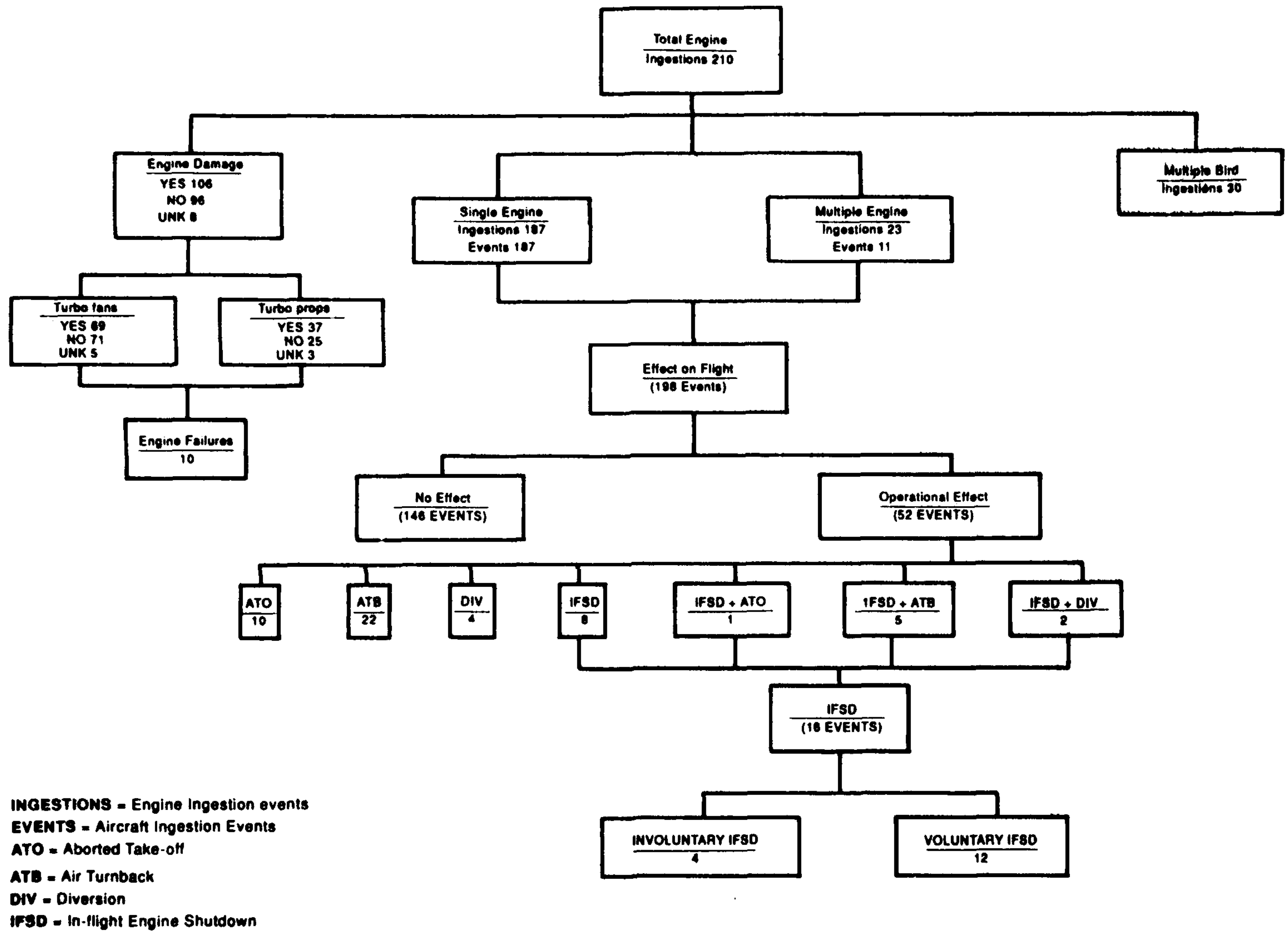


FIGURE E-1. SMALL INLET AREA TURBINE ENGINE BIRD INGESTION STUDY
DATA SUMMARY
(2 YEARS OF DATA, 5/87 TO 4/89)

It was observed that the same number of engine ingestion events occurred in the combined takeoff/climb phases of flight as in the combined approach/landing phases of flight. The ratio of landing events to approach was close to one 55:45), whereas the ratio of takeoff events to climb events exceeded ten (91:9). Less than 5 percent of all ingestion events occurred during taxi or at cruise altitude.

Engine damage occurred in 50 percent of all engine ingestion events, and it was not the case that there was a threshold bird weight such that smaller birds did no damage and larger birds always caused damage. Instead, the probability of damage increased with bird weight. However, in some events small birds caused damage, while in other events larger birds caused no damage at all. Probability-of-damage versus bird-weight curves were computed from the data. Also, the probability of engine damage is greater when the bird ingestion occurs during the takeoff and climb phases of flight than when it occurs during approach and landing. Aircraft airspeed at or above 140 knots also increases the probability of engine damage.

It was determined that 5 percent of all engine bird ingestion events resulted in an engine failure. Four engine failures were caused by birds that weighed more than 4 pounds and two were caused by birds that weighed less than 1/2 pound. Engine failures are also more likely to occur when multiple birds are ingested into an engine.

It was observed that as the level of damage increased, the probability of crew action likewise increased. For turbofan engines, the probability of crew action was 6.6 percent after engine ingestion events in which there was no damage, while probability of crew action was 42 percent after engine ingestion events in which there was severe damage. For the turboprop engine, the probability of crew action for events with no engine damage was 16 percent.

It was found that the probability of ingestion for birds in the weight range from 0 to 4 ounces (the most common range) was 1.98 per million operations. Overall, the probability of ingesting a bird was 13 per million engine operations.

A summary of the most pertinent statistics extracted from the 2 years of data is provided below:

| | |
|---|---|
| Most Frequently Ingested Bird Weight (oz) | |
| United States | 4 |
| Foreign | 7.7 |
| Average Bird Weight (oz) | |
| United States | 21 |
| Foreign | 9.2 |
| Median Bird Weight (oz) | |
| United States | 4 |
| Foreign | 7.7 |

| | |
|---|---|
| Probability of Ingestion per Engine Operation | |
| Worldwide (all engine types) | $1.3 \times 10^{-5}$ |
| United States (JT15D engine excluded) | $1.04 \times 10^{-5}$ |
| Foreign (JT15D engine excluded) | $1.922 \times 10^{-5}$ |
| Most Commonly Ingested Bird | |
| United States | Dove |
| Foreign | Lapwing |
| Engines Experiencing Moderate/Severe Damage | |
| Turbofans | 41 |
| Turboprops | 2 |
| Ingestions During Phase of Flight | |
| Takeoff and Climb | 100 |
| Approach and Landing | 100 |

## SECTION 1
## INTRODUCTION

### 1.1 BACKGROUND.

Contention for airspace between birds and airplanes has created a serious bird/aircraft strike hazard. Four past studies [references 1,2,3 and 4] have indicated that birdstrikes to engines are statistically rare events. The probability of a birdstrike during any given flight is extremely low; however, given the number of flights currently taking place, the expected number of birdstrikes becomes significant.

The windshield and the engines are particularly vulnerable to the birdstrike threat. Although penetration of the windshield by a bird is primarily a concern for military airplanes operating at high speeds in a low-altitude environment, such a penetration occurred on a civilian airplane resulting in the death of the copilot. Ingestion of birds into airplane engines is a safety problem for civil as well as military airplanes for it can cause significant damage to the engine, resulting in degraded engine performance and possibly failure.

In his study of bird ingestions on commercial flights, Frings [reference 1] indicated that nearly all bird ingestion events have occurred in the vicinity of airports during the noncruise phases of flight. Hovey and Skinn [references 2 and 3] reached similar conclusions. This is understandable because these phases of flight naturally occur closer to the ground where bird concentrations are higher, resulting in a higher probability of birdstrike.

The solution to the problem of engine damage resulting from bird ingestion is similar to that for windshield birdstrike, e.g., either design-consideration of the structure to withstand impact, and/or avoidance of birds. Bird avoidance can be facilitated by either of two approaches: (1) keeping airplanes out of airspaces with large bird concentrations, or (2) removing birds from these regions of airspace. The bird avoidance approach can have various degrees of success or failure for commercial air fleets because flight schedules place airplanes in specific areas at specific times and the effectiveness of airport bird control programs (if any) varies from airport to airport and country to country.

Structural design of engines to withstand bird ingestion damage can be accomplished given that realistic requirements with respect to bird sizes and numbers can be identified. Bird ingestion data for various sizes of turbofan and turboprop engines are currently being collected by several engine manufacturers. Statistical evaluation of bird ingestion data from these data collection efforts and previous bird ingestion studies will be useful in re-evaluating certification test regulations laid out in FAA Regulation 14 CFR 33.77. As a result, future engines can be designed to withstand more realistic bird threats.

### 1.2 OBJECTIVE.

The objective of this report is to determine the relationship of bird weight, geographic location, season, time of day, phase of flight, and engine type to the frequency of bird ingestion events and the extent of engine damage resulting from the ingested birds. A statistical analysis was conducted of reported bird ingestion data experienced by commercial and general aviation aircraft equipped with any of four engine types (ALF502, TPE331, TFE731 and JT15D) operating worldwide over a 2-year reporting period from May 1987 through April 1989. The analysis was used to summarize the bird ingestion damage experienced by these engines. The findings of the analysis will be used to determine the adequacy of the bird ingestion test criteria as specified in FAA regulation 14 CFR 33.77 for this class of small inlet area engines. Small inlet area engines are being defined as those engines having an inlet area up to approximately 1400 square inches.

## 1.3 ORGANIZATION OF REPORT.

Section 2 presents engine hours and operations for the four engines. Section 3 identifies the characteristics of bird species that have been ingested and reliably identified. Section 4 describes bird ingestion rates by location, engine type, and phase of flight. Section 5 summarizes engine damage resulting from bird ingestions. Section 6 examines the probabilities of various bird ingestion events. Section 7 discusses data quality. Section 8 provides a summary of the results obtained during this phase of data analysis. Section 9 lists references used in preparation of this report. Section 10 is a glossary of terms. Appendix A provides information about size and use of the engines covered in this report. Appendix B provides the original data used in the analysis. Appendix C discusses the methods of statistical analysis used in the report, particularly hypothesis testing.

## SECTION 2
## ENGINE OPERATIONS

The number of engine operations is required to determine bird ingestion rates. Operations data that have been used to generate bird ingestion rates throughout the report are provided to aid in understanding this section. The reader should refer to the Glossary of Terms for definitions of the terms used.

For the ALF502, data on engine hours and engine operations were available from the manufacturer through the FAA. For the TPE331, JT15D, and TFE731, only data on engine hours were available. To obtain engine operations, average values of 0.8 operations/hours (TFE731), 0.9 operations/hours (JT15D), and 1.2 operations/ hours (TPE331) were provided through the FAA. Numbers of engine operations by month for the ALF502, TFE731, and TPE331 engines are presented in tables 2.1, 2.2 and 2.3, respectively. Because total operations for the TFE731 and TPE331 engines are obtained by using the aforementioned flight hour conversion factors, certain monthly, United States, foreign, and overall total operations in tables 2.2 and 2.3 appear as incorrect sums of individual monthly operations. Rounding error accounts for the arithmetic discrepencies. Figures 2.1, 2.2 and 2.3 are histograms displaying operations by month and engine.

Data for the JT15D were provided only as a total: 872,510 hours for the period May 1, 1988, to April 30, 1989. A conversion factor of 0.9 operations/hours results in a total of 785,259 operations for this engine. No information by month is available for this engine.

TABLE 2.1. HOURS AND OPERATIONS ALF502

| Date | United States | | Foreign | | Total | |
|---|---|---|---|---|---|---|
| Month Year | Hours | Operations | Hours | Operations | Hours | Operations |
| MAY87 | 39290 | 44167 | 8275 | 7538 | 47565 | 51705 |
| JUN87 | 39290 | 44167 | 8275 | 7538 | 47565 | 51705 |
| JUL87 | 46118 | 53719 | 10336 | 8689 | 56454 | 62408 |
| AUG87 | 47163 | 54699 | 12139 | 10130 | 59302 | 64829 |
| SEP87 | 43865 | 51507 | 9219 | 7842 | 53084 | 59349 |
| OCT87 | 46311 | 52987 | 12621 | 9795 | 58932 | 62782 |
| NOV87 | 43550 | 50574 | 12377 | 10205 | 55927 | 60779 |
| DEC87 | 43032 | 49247 | 11995 | 10418 | 55027 | 59665 |
| JAN88 | 46366 | 50244 | 10427 | 10706 | 56793 | 60950 |
| FEB88 | 46366 | 48185 | 10184 | 11922 | 56550 | 60107 |
| MAR88 | 41430 | 48185 | 9304 | 11866 | 50734 | 60051 |
| APR88 | 45168 | 49224 | 16300 | 18364 | 61468 | 67588 |
| MAY88 | 43484 | 50812 | 17136 | 16020 | 60620 | 66832 |
| JUN88 | 43724 | 50932 | 21352 | 19104 | 65076 | 70036 |
| JUL88 | 44040 | 51086 | 21956 | 19408 | 65996 | 70494 |
| AUG88 | 45868 | 53220 | 22224 | 20340 | 68092 | 73560 |
| SEP88 | 41148 | 47956 | 23968 | 22932 | 65116 | 70888 |
| OCT88 | 45200 | 51656 | 24284 | 23148 | 69484 | 74804 |
| NOV88 | 42836 | 48216 | 24536 | 24604 | 67372 | 72820 |
| DEC88 | 43328 | 48448 | 25760 | 24564 | 69088 | 73012 |
| JAN89 | 43748 | 49212 | 26654 | 25851 | 70402 | 75063 |
| FEB89 | 40056 | 44110 | 25738 | 26367 | 65794 | 70477 |
| MAR89 | 30700 | 48780 | 32319 | 33715 | 63019 | 82495 |
| APR89 | 40020 | 46648 | 33060 | 34288 | 73080 | 80936 |
| Total | 1032101 | 1187981 | 430439 | 415354 | 1462540 | 1603335 |

TABLE 2.2. HOURS AND OPERATIONS TFE731

| Date | | United States | | Foreign | | Total | |
|---|---|---|---|---|---|---|---|
| Month | Year | Hours | Operations | Hours | Operations | Hours | Operations |
| MAY87 | | 127148 | 101718 | 45189 | 36151 | 172337 | 137870 |
| JUN87 | | 128132 | 102506 | 46060 | 36848 | 174192 | 139354 |
| JUL87 | | 130058 | 104046 | 46028 | 36822 | 176086 | 140869 |
| AUG87 | | 132051 | 105641 | 48274 | 38619 | 180325 | 144260 |
| SEP87 | | 131189 | 104951 | 46967 | 37574 | 178156 | 142525 |
| OCT87 | | 132677 | 106142 | 48595 | 38876 | 181272 | 145018 |
| NOV87 | | 134888 | 107910 | 49968 | 39974 | 184856 | 147885 |
| DEC87 | | 135142 | 108114 | 51393 | 41114 | 186535 | 149228 |
| JAN88 | | 131583 | 105266 | 50585 | 40468 | 182168 | 145734 |
| FEB88 | | 134338 | 107470 | 49942 | 39954 | 184280 | 147424 |
| MAR88 | | 140277 | 112222 | 52557 | 42046 | 192834 | 154267 |
| APR88 | | 141617 | 113294 | 53424 | 42739 | 195041 | 156033 |
| MAY88 | | 132631 | 106105 | 49215 | 39372 | 181846 | 145477 |
| JUN88 | | 131509 | 105207 | 49084 | 39267 | [illegible]0593 | 144474 |
| JUL88 | | 131517 | 105214 | 50924 | 40739 | [illegible]82441 | 145953 |
| AUG88 | | 131881 | 105505 | 51783 | 41426 | 183664 | 146931 |
| SEP88 | | 130933 | 104746 | 50872 | 40698 | 181805 | 145444 |
| OCT88 | | 134926 | 107941 | 52596 | 42077 | 187522 | 150018 |
| NOV88 | | 144838 | 115870 | 54334 | 43467 | 199172 | 159338 |
| DEC88 | | 138015 | 110412 | 51316 | 41053 | 189331 | 151465 |
| JAN89 | | 135526 | 108421 | 50296 | 40237 | 185822 | 148658 |
| FEB89 | | 142042 | 113634 | 51414 | 41131 | 193456 | 154765 |
| MAR89 | | 139941 | 111953 | 54156 | 43325 | 194097 | 155278 |
| APR89 | | 148383 | 118706 | 56031 | 44825 | 204414 | 163531 |
| Total | | 3241242 | 2592994 | 1211003 | 968802 | 4452245 | 3561796 |

Note: Detail may not add to total because of rounding.

TABLE 2.3. HOURS AND OPERATIONS TPE331

| Date | | United States | | Foreign | | Total | |
|---|---|---|---|---|---|---|---|
| Month | Year | Hours | Operations | Hours | Operations | Hours | Operations |
| MAY87 | | 206666 | 247999 | 81385 | 97662 | 288051 | 345661 |
| JUN87 | | 211357 | 253628 | 89138 | 106966 | 300495 | 360594 |
| JUL87 | | 234047 | 280856 | 93231 | 111877 | 327278 | 392734 |
| AUG87 | | 232892 | 279470 | 93280 | 111936 | 326172 | 391406 |
| SEP87 | | 232924 | 279509 | 95408 | 114490 | 328332 | 393998 |
| OCT87 | | 237444 | 284933 | 97521 | 117025 | 334965 | 401958 |
| NOV87 | | 237631 | 285157 | 101077 | 121292 | 338708 | 406450 |
| DEC87 | | 230677 | 276812 | 95275 | 114330 | 325952 | 391142 |
| JAN88 | | 237817 | 285380 | 97319 | 116783 | 335136 | 402163 |
| FEB88 | | 251480 | 301776 | 88360 | 106032 | 339840 | 407808 |
| MAR88 | | 250675 | 300810 | 93553 | 112264 | 344228 | 413074 |
| APR88 | | 261232 | 313478 | 100541 | 120649 | 361773 | 434128 |
| MAY88 | | 249151 | 298981 | 116604 | 139925 | 365755 | 438906 |
| JUN88 | | 253131 | 303757 | 116706 | 140047 | 369837 | 443804 |
| JUL88 | | 249269 | 299123 | 119622 | 143546 | 368891 | 442669 |
| AUG88 | | 250314 | 300377 | 120657 | 144788 | 370971 | 445165 |
| SEP88 | | 263965 | 316758 | 116854 | 140225 | 380819 | 456983 |
| OCT88 | | 252292 | 302750 | 118798 | 142558 | 371090 | 445308 |
| NOV88 | | 255233 | 306280 | 120698 | 144838 | 375931 | 451117 |
| DEC88 | | 255934 | 307121 | 122375 | 146850 | 378309 | 453971 |
| JAN89 | | 268975 | 322770 | 121914 | 146297 | 390889 | 469067 |
| FEB89 | | 259072 | 310886 | 122810 | 147372 | 381882 | 458258 |
| MAR89 | | 254644 | 305573 | 124848 | 149818 | 379492 | 455390 |
| APR89 | | 266753 | 320104 | 126383 | 151660 | 393136 | 471763 |
| Total | | 5903575 | 7084288 | 2574357 | 3089229 | 8477932 | 10173518 |

Note: Detail may not add to total because of rounding.

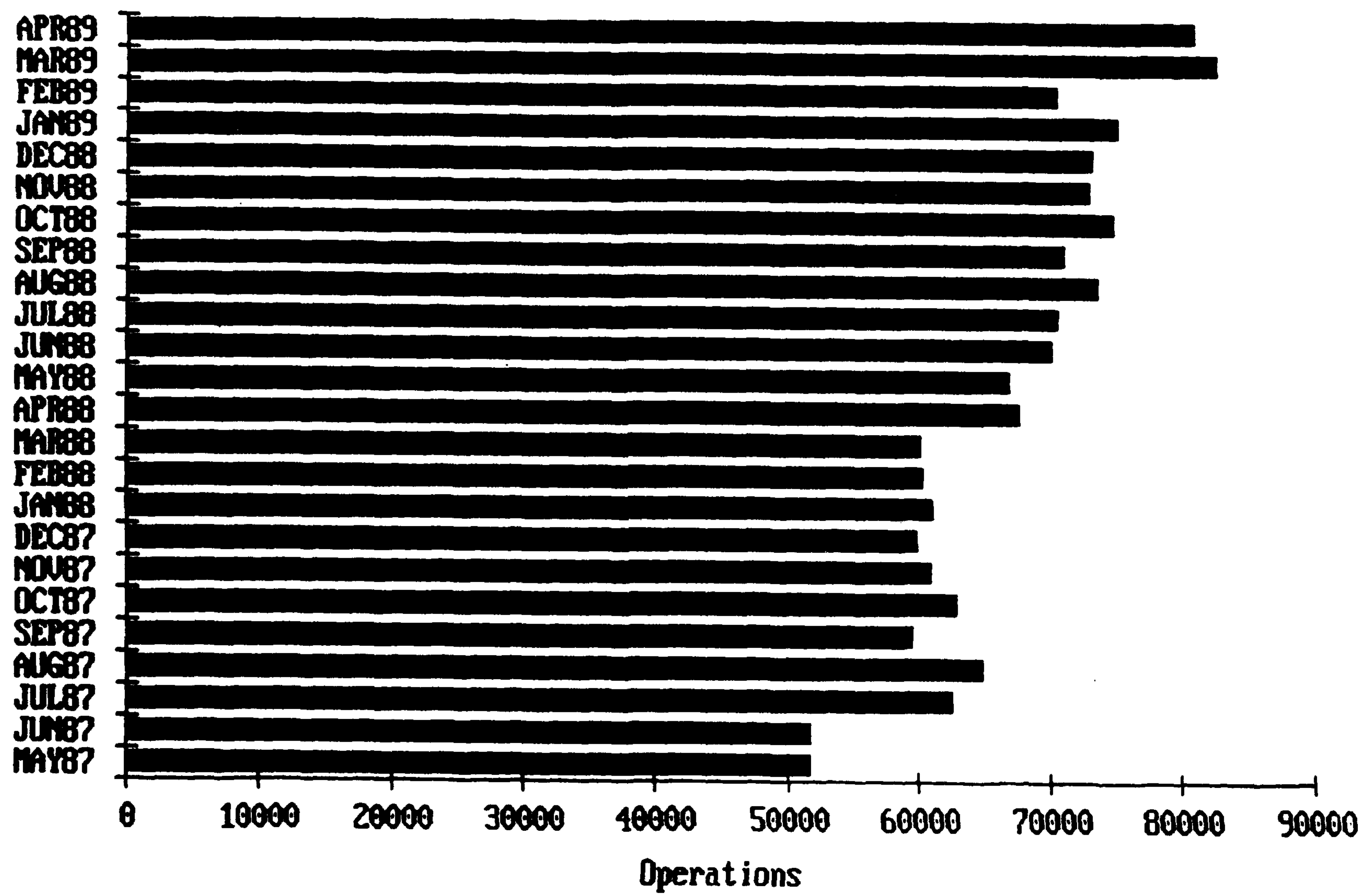


FIGURE 2.1. OPERATIONS, ALF502 ENGINE

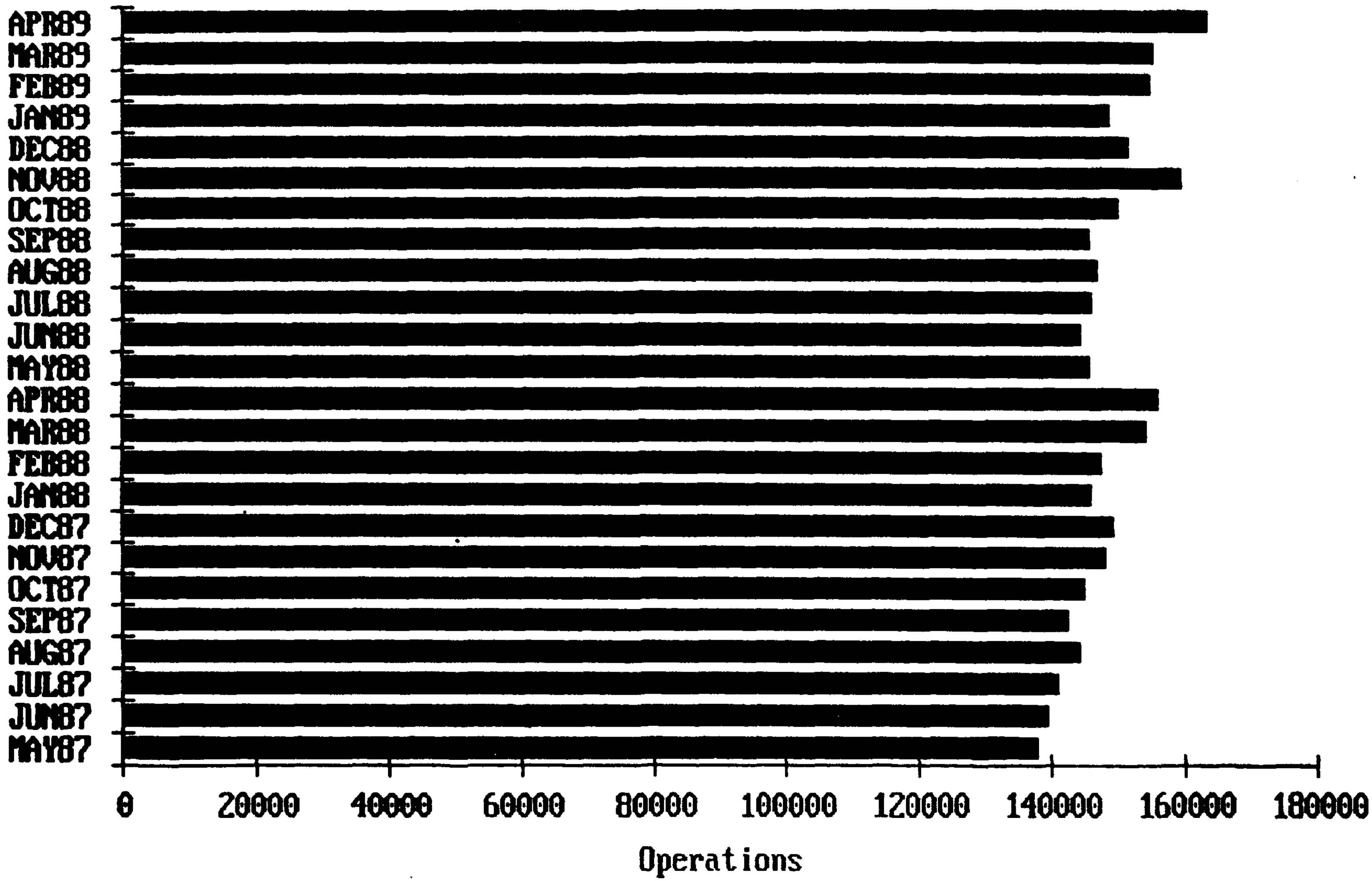


FIGURE 2.2. OPERATIONS, TFE731 ENGINE

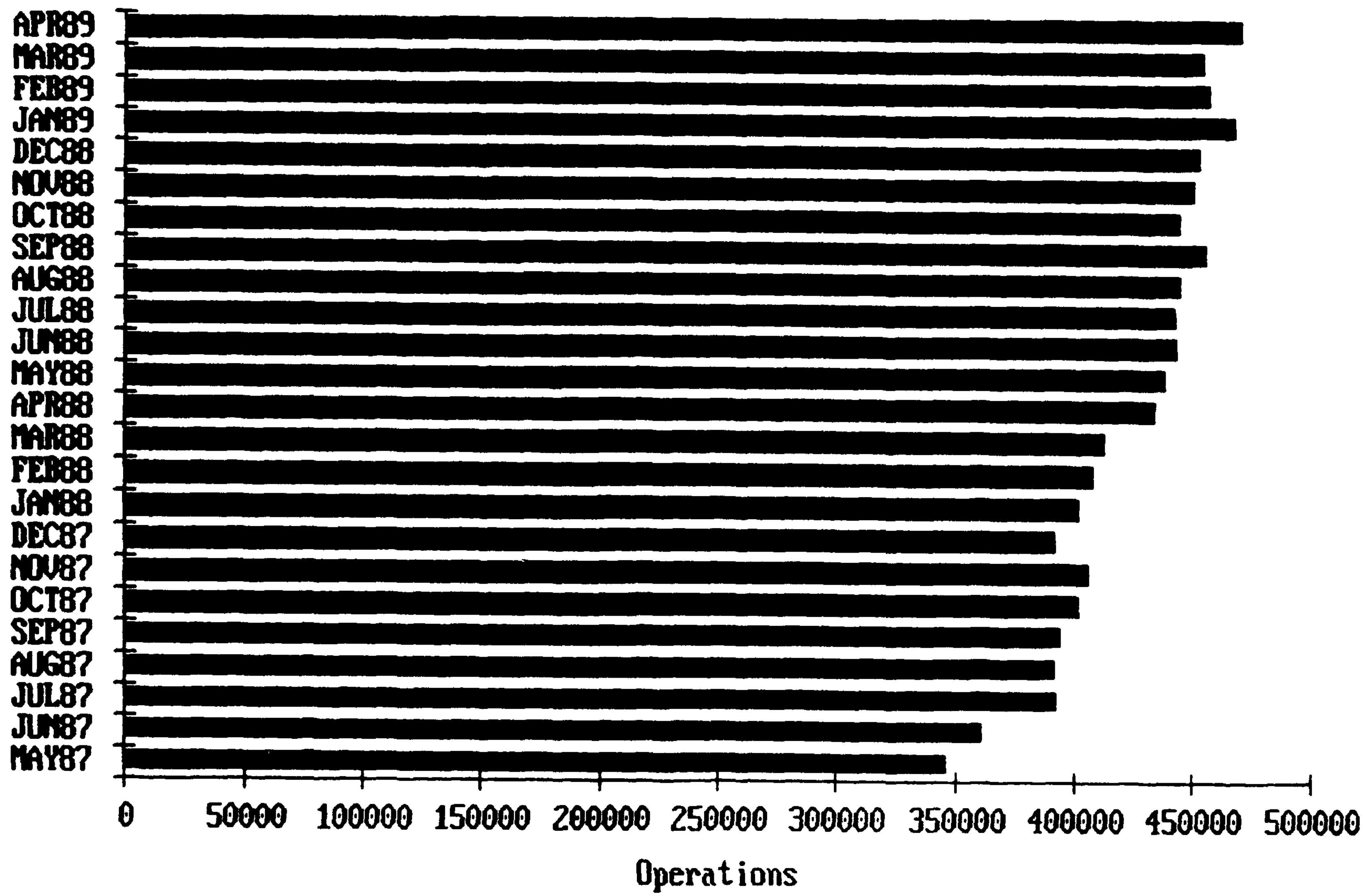


FIGURE 2.3. OPERATIONS, TPE331 ENGINE

## SECTION 3
## CHARACTERISTICS OF INGESTED BIRDS

The purpose of this section is to provide a description of the birds that were ingested during the period covered by the data and to provide an analysis of the extent of the bird ingestion threat. The bird related features that are described in this section include species, weight, seasonal trends, time-of-day trends, and geographic location.

Table 3.1 provides a tally of all the species that were positively identified by an ornithologist during the period covered by the data. The species are listed by order and family. One of the disappointing features of the small engine bird ingestion data base is the low bird identification rate. Out of the total of 198 aircraft ingestion events that were recorded, the bird species was positively identified in only 70 events, for a total identification rate of 35.4 percent.

Table 3.2 presents the distribution of weights for the positively identified birds. The numbers in table 3.2 reflect the number of times birds of a given weight were encountered. That is, if more than one bird was ingested in one or more engines, the bird weight was counted once only. Thus the table is not skewed by multiple-bird or multiple-engine ingestions from the same flock of birds. The bird weights are derived from the species identification and when possible are adjusted for the age and sex of the ingested bird. Figure 3.1 presents the same data in the form of a histogram.

There were 30 cases where multiple birds were ingested into the same engine, and 11 cases where bird ingestions occurred in multiple engines during the same event. These cases, of multiple bird ingestions and multiple engine events, are important from a safety standpoint. However, the data contain too few cases to allow any conclusions to be drawn.

A comparison of the distribution of bird weights for United States and foreign ingestion events was carried out using the Kolmogorov-Smirnov test. The maximum deviation between the distributions was 0.176. By chance, a deviation of 0.39 would be exceeded five times in a hundred. Hence at a significance level of 0.05, the hypothesis that the weights of ingested birds in the United States and outside the United States are the same cannot be rejected. (For a brief explanation of statistical terms see appendix C.)

Summary statistics calculated from the raw data for the United States, foreign, and worldwide bird weight distributions are presented in table 3.3. The statistics presented are the mode, the median, and the mean. These three statistics each represent an attempt to identify a "typical" member of a distribution. The mode is the most common value in the distribution, the median is the value which splits the distribution into two equal halves, and the mean is weighted by each value appearing in the distribution as well as the number of times it appears.

The mode is a relevant measure of the bird ingestion problem. It represents the weight which will be encountered most frequently. In the United States, the modal weight is 4 ounces, while outside the United States the modal weight is 7.7 ounces. Worldwide the modal weight is also 4 ounces. These modal weights correspond to the most frequently encountered species in each case. It is possible to have multimodal distributions, but the weight distributions of birds ingested during the period covered by the data turned out to be unimodal.

TABLE 3.1. TALLY OF POSITIVELY IDENTIFIED BIRD SPECIES BROKEN DOWN BY US, FOREIGN, AND OVERALL

| Latin Name | Common Name | Species | US | Foreign | Unknown | Overall |
|---|---|---|---|---|---|---|
| Givia | Common loon | 1E3 | 1 | 0 | 0 | 1 |
| Nyctanassa violacea | Yellow-crowned night heron | 1I27 | 1 | 0 | 0 | 1 |
| Chen caerulescens | Snow Goose | 2J26 | 2 | 0 | 0 | 2 |
| Branta canadensis | Canada goose | 2J30 | 2 | 0 | 0 | 2 |
| Anas americana | American wigeon | 2J71 | 1 | 0 | 0 | 1 |
| Anas platyrhynchos | Mallard | 2J84 | 0 | 1 | 0 | 1 |
| Aythya affinis | Lesser scaup | 2J125 | 1 | 0 | 0 | 1 |
| Cathartes aura | Turkey vulture | 1K1 | 1 | 0 | 0 | 1 |
| Haliastur indus | Brahminy kite | 3K31 | 0 | 1 | 0 | 1 |
| Falco sparverius | American kestrel | 5K26 | 1 | 1 | 0 | 2 |
| Falco tinnunculus | Eurasian kestrel | 5K27 | 0 | 1 | 0 | 1 |
| Perdix perdix | Hungarian partridge | 4L85 | 0 | 1 | 0 | 1 |
| Phasianus colchicus | Ring-neck pheasant | 4L161 | 1 | 0 | 0 | 1 |
| Gallinula chloropus | Common gallinule | 7M112 | 1 | 0 | 0 | 1 |
| Vanellus vanellus | Common lapwing | 5N1 | 0 | 5 | 0 | 5 |
| Charadrius vociferus | Killdeer | 5N33 | 6 | 0 | 0 | 6 |
| Charadrius mongolus | Mongolian plover | 5N45 | 0 | 1 | 0 | 1 |
| Tringa melanoleuca | Greater yellowlegs | 6N19 | 1 | 0 | 0 | 1 |
| Tringa flavipes | Lesser yellowlegs | 6N20 | 1 | 0 | 0 | 1 |
| Scolopax minor | American woodcock | 6N37 | 1 | 0 | 0 | 1 |
| Larus delawarensis | Ring-billed gull | 14N12 | 3 | 2 | 0 | 5 |
| Larus Canus | Common gull | 14N13 | 1 | 0 | 0 | 1 |
| Larus argentatus | Herring gull | 14N14 | 1 | 0 | 0 | 1 |
| Larus pipixcan | Franklin's gull | 14N31 | 1 | 0 | 0 | 1 |
| Larus ridibundus | Common black-headed gull | 14N36 | 0 | 1 | 0 | 1 |
| Columba livia | Common rock dove | 2P1 | 4 | 0 | 0 | 4 |
| Columba palumbus | Common wood-pigeon | 2P9 | 0 | 1 | 0 | 1 |
| Streptonpelia chinensis | Spotted dove | 2P65 | 0 | 1 | 0 | 1 |
| Zenaida macroura | American mourning dove | 2P105 | 9 | 0 | 0 | 9 |
| Tyto alba | Common barn owl | 1S2 | 1 | 0 | 0 | 1 |
| Asio otus | Northern long-eared owl | 2S120 | 0 | 1 | 0 | 1 |
| Apus melba | Alpine swift | 1U52 | 0 | 1 | 0 | 1 |
| Apus apus | Common swift | 1U55 | 0 | 1 | 0 | 1 |
| Eremophila alpestris | Horned lark | 17Z74 | 2 | 0 | 0 | 2 |
| Hirundo rustica | Barn swallow | 18Z37 | 1 | 0 | 0 | 1 |
| Delichon urbica | Common house martin | 18Z69 | 0 | 1 | 0 | 1 |
| Sturnus vulgaris | Common starling | 21Z75 | 1 | 0 | 1 | 2 |
| Turdus philomelos | Common song thrush | 41Z282 | 0 | 1 | 0 | 1 |
| Agelaius phoeniceus | Red-winged blackbird | 64Z54 | 1 | 0 | 0 | 1 |
| Sturnella magna | Eastern meadowlark | 64Z67 | 1 | 0 | 0 | 1 |
| Passer domesticus | House sparrow | 70Z12 | 1 | 0 | 0 | 1 |
| Passer montanus | Eurasian tree sparrow | 70Z23 | 0 | 1 | 0 | 1 |
| | | | --- | --- | --- | --- |
| | | | 48 | 22 | 1 | 71 |

TABLE 3.2. DISTRIBUTION OF BIRD WEIGHTS (AIRCRAFT INGESTION EVENTS)

| Weight (oz) | US | Foreign | Unknown | Total |
|---|---|---|---|---|
| $0 < x \leq 4$ | 23 | 8 | 1 | 32 |
| $4 < x \leq 8$ | 2 | 7 | 0 | 9 |
| $8 < x \leq 12$ | 3 | 2 | 0 | 5 |
| $12 < x \leq 16$ | 6 | 4 | 0 | 10 |
| $16 < x \leq 20$ | 2 | 2 | 0 | 4 |
| $20 < x \leq 24$ | 1 | 0 | 0 | 1 |
| $24 < x \leq 28$ | 1 | 0 | 0 | 1 |
| $32 < x \leq 36$ | 0 | 1 | 0 | 1 |
| $36 < x \leq 40$ | 2 | 0 | 0 | 2 |
| $64 < x \leq 68$ | 1 | 0 | 0 | 1 |
| $88 < x \leq 92$ | 2 | 0 | 0 | 2 |
| $100 < x \leq 104$ | 1 | 0 | 0 | 1 |
| $124 < x \leq 128$ | 2 | 0 | 0 | 2 |
| Totals | 46 | 24 | 1 | 71 |

(Note: this table includes one bat, not included in table 3.1)

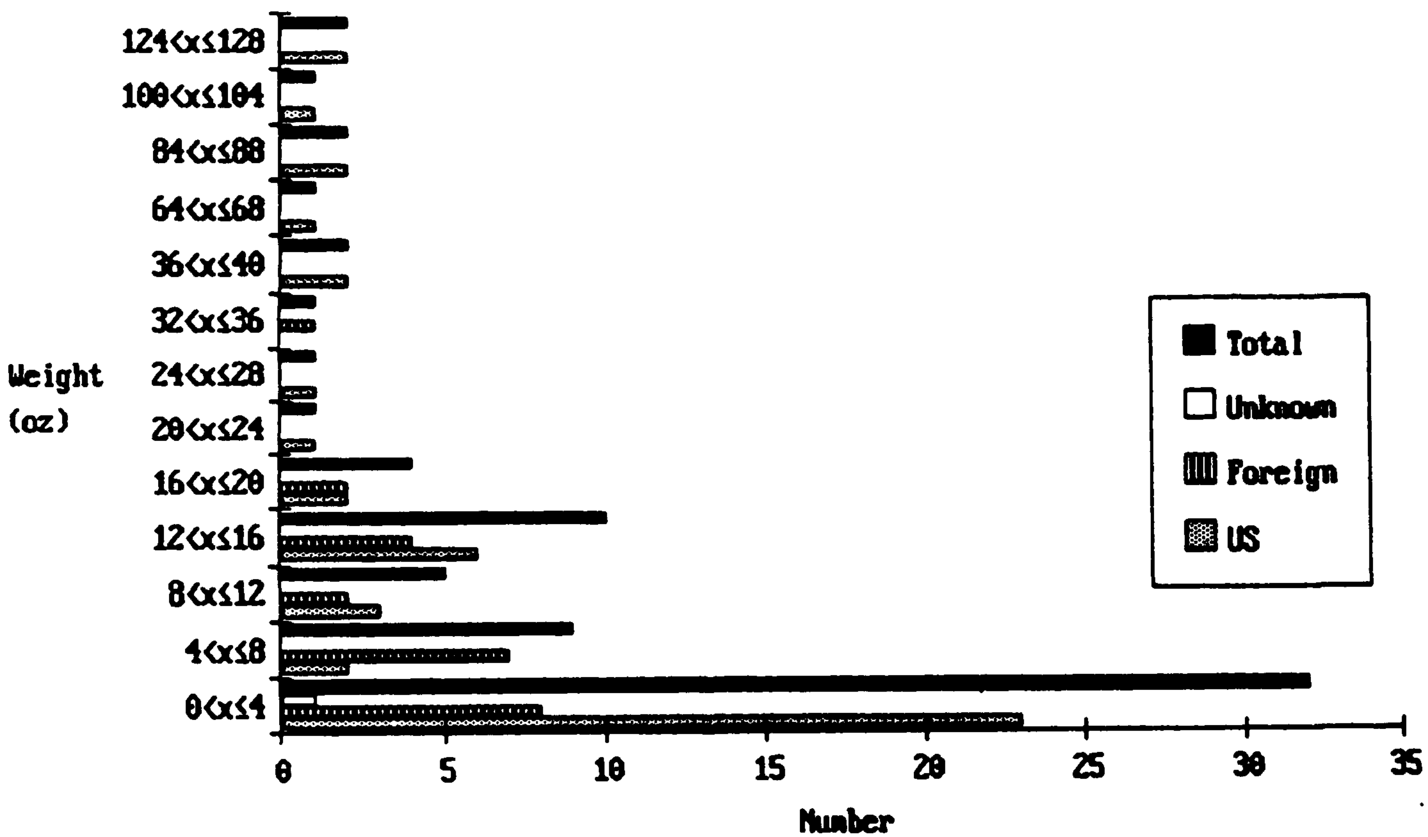


FIGURE 3.1. DISTRIBUTION OF BIRD WEIGHTS

TABLE 3.3. SUMMARY STATISTICS FOR INGESTED BIRD WEIGHTS

| Statistic | US | Foreign | Worldwide |
|---|---|---|---|
| Mode | 4 | 7.7 | 4 |
| Median | 4 | 7.7 | 7.7 |
| Lower Quartile | 3 | 2 | 3 |
| Upper Quartile | 17 | 14 | 16 |
| Interquartile Range | 14 | 12 | 13 |
| Mean | 21.01 | 9.21 | 16.77 |
| Standard Deviation | 33.20 | 8.19 | 27.65 |

Note: All weights in ounces.

The median is the value which divides the distribution in half. Median weights are 4 ounces in the United States, 7.7 ounces outside the United States, and 7.7 worldwide. The quartiles divide the upper and lower halves of a distribution in half. Each is a value one-quarter of the way in from the end of the distribution. In the United States, 25 percent of the birds had weight equal to or exceeding 17 ounces, while outside the United States the top 25 percent of birds had weights equal to or exceeding 14 ounces. In the United States, 25 percent of the birds weighed 3 ounces or less, while outside the United States the lowest 25 percent of the weights included birds only up to 2 ounces. The Interquartile Range (IQR) is the distance between the upper and lower quartiles -- the "middle half" of the distribution. It is a measure of the dispersion of values in the distribution. In the United States the IQR is 14 ounces, while outside the United States it is 12 ounces. Worldwide it is 13 ounces. This simply means that inside and outside the United States, the degree of clustering about the median is nearly the same, even though the medians differ by roughly a factor of two. However, outside the quartiles the spread of bird weights is greater in the United States. This can be seen from table 3.2, which shows that outside the United States the weight of ingested birds did not exceed 36 ounces, while in the United States there were birds with weights up to 128 ounces.

The mean is obtained by weighting each value in the distribution by the number of times which it occurs. Moreover, it is a function of the sum of all the values in the distribution. The mean tends to be influenced by extreme values. In the case of the bird weight distributions, the mean is influenced by the high values, and thus overestimates the weight of the "typical" ingested bird. The mean would be a relevant measure of ingested bird weight if damage were related to the cumulative weight of all birds ingested by a single engine, since it does depend upon the total weight of the ingested birds. However, since bird ingestion is such a rare event, the mean is not a particularly useful measure of ingested bird weight.

From the standpoint of descriptive statistics, then, the important results from table 3.3 are that the most frequently ingested birds weigh 4 ounces: but 50 percent of all ingested birds weigh 7.7 ounces or more, and fully 25 percent of all ingested birds weigh more than 16 ounces.

One issue which might be raised is the extent to which the ingestion events in which the bird weight is known are representative of all ingestion events. It might be hypothesized that the bird species is more likely to be identified (and therefore the weight known) in those cases in which greater damage has been incurred, while bird weight is less likely to be known if lesser or no damage occurred. The chi-square test was applied to this hypothesis. A chi-square value of 4.8 was obtained, comparing the actual numbers of identified birds with the hypothesis that the same fraction of birds were identified regardless of damage level. With 3 degrees of freedom, a value for chi-square of 6.25 would be exceeded with a probability of 10 percent. Hence the hypothesis that the same fraction of birds are identified regardless of the damage level cannot be rejected, and one can conclude that the ingestion events in which bird weight is known are representative of all ingestion events.

Figure 3.2 presents a histogram of ingestions by month for the 2-year period covered by the data. Each bar in figure 3.2 represents the sum of ingestions from its respective month in 2 consecutive years. It is known that the number of ingestions per month should be influenced by seasonality (bird migrations) and by

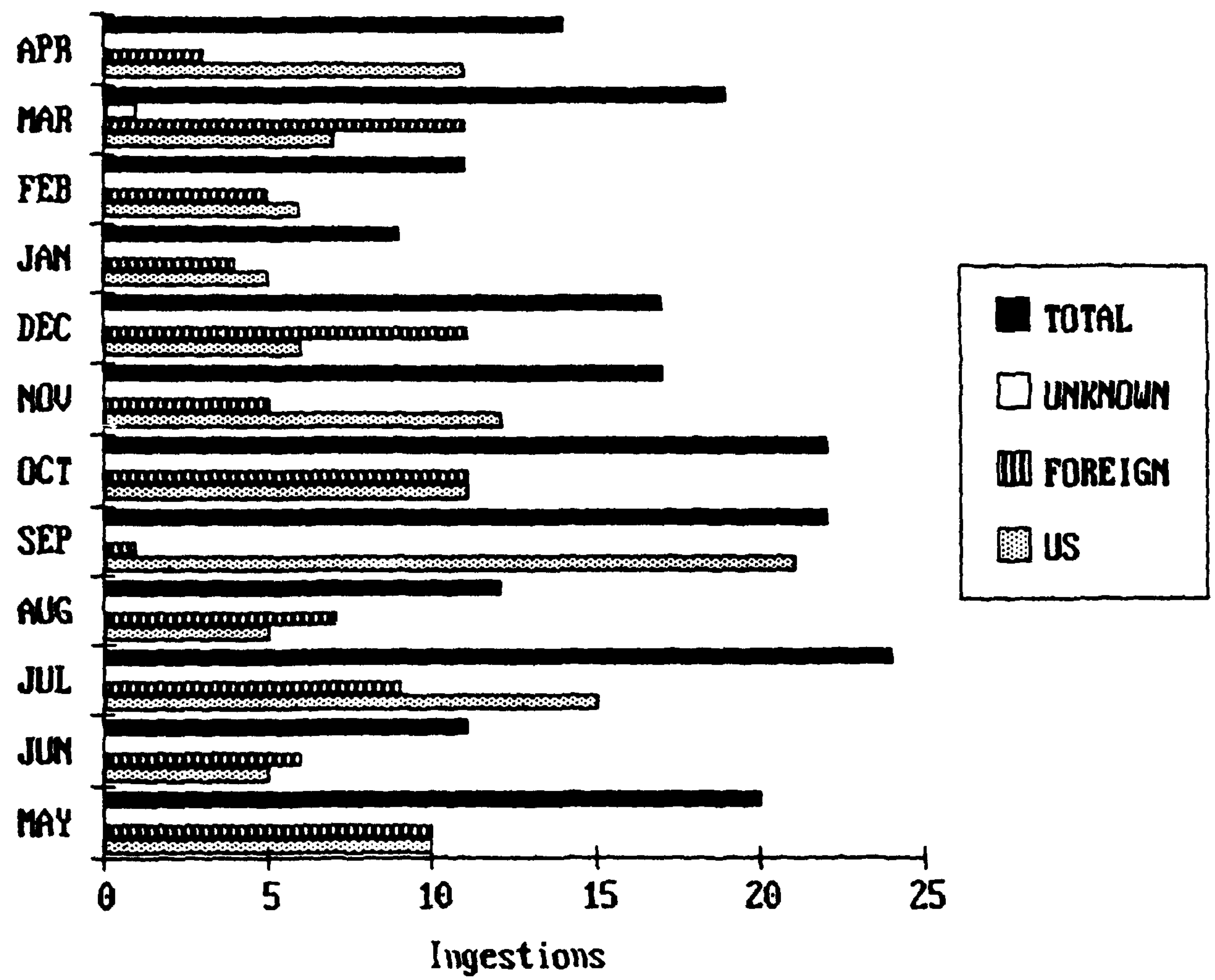


FIGURE 3.2. AIRCRAFT INGESITONS BY MONTH FOR 2 YEARS

number of operations. However, the effects of these factors could not be separately identified in the data. Since ingestion locations were known, the numbers of ingestions could be categorized as United States or foreign, and also as Northern or Southern Hemisphere. Numbers of engine operations could be separated only into United States or foreign. Hence ingestions in either hemisphere could not be normalized to numbers of operations.

The variation in number of ingestions from month to month is not only highly volatile but appears random. Several tests for randomness, trend, or seasonality were applied.

A chi-square test was used to test for differences between patterns of monthly ingestions inside and outside the United States (including both hemispheres). The test found a significant difference. However, there is some question of whether this finding should be taken seriously. Nearly half the total value of chi-square came from the months of September, in which the United States had a total of 21 ingestions while there was only one ingestion outside the United States.

A Kolmogorov-Smirnov test was likewise applied to United States versus foreign monthly ingestions. This test found that the difference between the two sets of ingestions was not significant at the 1 percent level. This reinforces the suggestion that the chi-square test result was the result of statistical anomaly, that is, accepting the hypothesis of a difference would be to commit a Type I error.

A chi-square test was applied to the Northern Hemisphere data alone, to detect United States versus foreign differences uncontaminated by differing seasonality in Northern and Southern Hemispheres. The difference between the two was not found to be significant.

Several tests were applied to detect seasonality if it existed.

A chi-square test was used to determine if there were significant departures from a uniform distribution across the months. This test found a significant difference. However, again a significant share of the total chi-square value was accounted for by the months of September alone. Hence this test must be viewed as possibly spurious.

A linear regression was also performed on the Northern Hemisphere ingestions on the months, in sequence, to detect any trends. The slope of the regression was -0.608 and the standard error of the slope was 0.459. Hence the slope was not significantly different from zero. On the basis of this test, the hypothesis of no trend in the data cannot be rejected.

A Fourier analysis of the month-to-month variation in ingestions in the Northern Hemisphere was carried out in an attempt to find periodicity in the data. The magnitude of the second harmonic (two peaks and two troughs) was only 23 percent of the average monthly ingestion rate. At best, this would be only weak evidence for periodicity (seasonality). Moreover, one of the troughs of the second-harmonic fit coincided with the month of the greatest number of ingestions, while one of the peaks of the second-harmonic fit coincided with the month in which ingestions were slightly below average. This result indicates that if seasonality is present in the Northern Hemisphere data, it is buried in the noise.

Figures 3.3, 3.4 and 3.5 present histograms of aircraft ingestion events by time of day for the period covered by the data. Figure 3.3 shows aircraft ingestion events by time of day. A chi-square analysis allows rejection of the hypothesis that number of ingestions is uniformly distributed throughout the day. The actual value of chi-square was 70.1, while a value of 9.4 would be exceeded by chance only 2.5 percent of the time. The variation in number of ingestions by time of day can be explained by either or both of two factors. First, many birds tend to be diurnal and are less likely to be exposed to ingestion at night. Second, most aircraft operations occur in the middlle of the day, with fewest at night. Numbers of operations in the morning and the evening are intermediate between the midday and night levels. Both these factors probably influence the variation by time of day in the number of ingestions.

During all time periods, the number of ingestions in the United States was greater than the number of ingestions outside the United States. However, a chi-square test showed that there was no significant difference in the patterns of ingestions in the United States and outside the United States by time of day. The actual value of chi-square was only 1.91. This value would be exceeded by chance 25 percent of the time. A chi-square value of 9.4 would be required for the difference to be statistically significant at 2.5 percent.

Figure 3.4 shows numbers of aircraft ingestion events in which more than one bird was ingested into the same engine. The total number of events is not sufficient to permit any statistical analysis. However, there were more ingestion events during the morning hours than in any other period of the day.

Figure 3.5 shows numbers of ingestion events in which birds were ingested in more than one engine. There were too few multiple engine ingestion events to permit any statistical analysis. The distribution appears uniform across the day, with the only difference between United States and foreign events being one foreign event of an ingestion during the night.

For some ingestions, time of day was not stated. These are shown as Unknown in figures 3.3, 3.4 and 3.5. Note that the total unknown count in figure 3.3 exceeds the sum of United States and foreign counts by one because the geographic location of one event is also unknown.

The geographic distribution of aircraft ingestion events within the United States is shown in figure 3.6. California had the largest number of aircraft ingestion events with 11. This may be due to a combination of a large coastal bird population and heavy air traffic. The state with the second largest number of aircraft ingestion events was Ohio with 5. However, there appears to be a concentration of events east of the Mississippi and south of the Great Lakes, extending to the Atlantic coast. This is probably the result of heavy air traffic in this region, with many cities, many airports, and frequent operations.

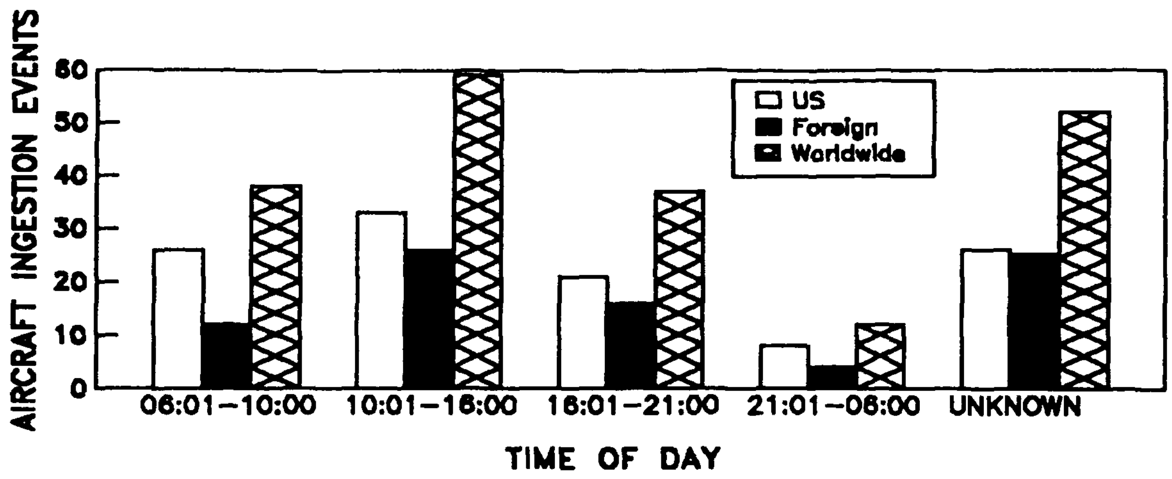


FIGURE 3.3. INGESTIONS BY TIME OF DAY

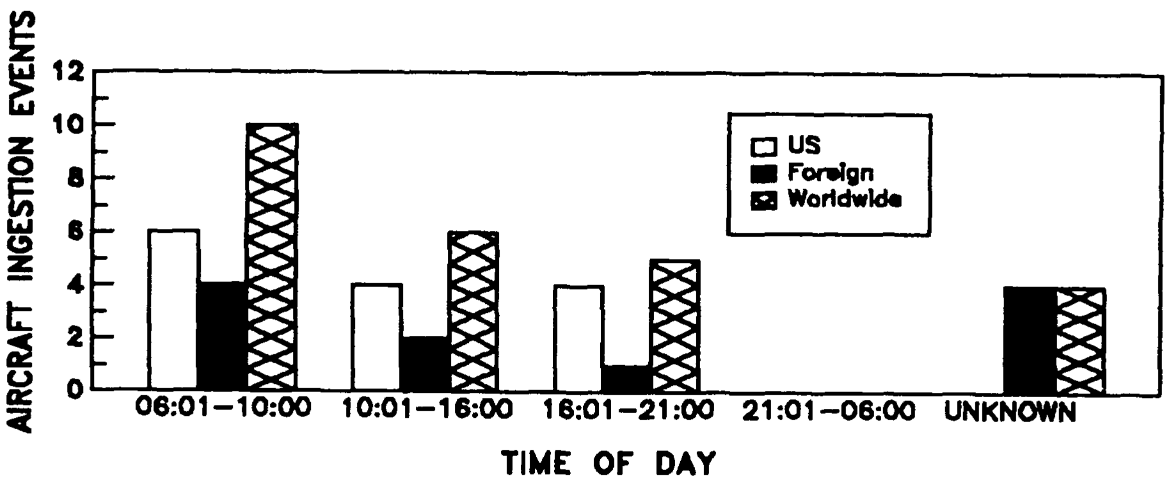


FIGURE 3.4. MULTIPLE BIRD INGESTIONS BY TIME OF DAY

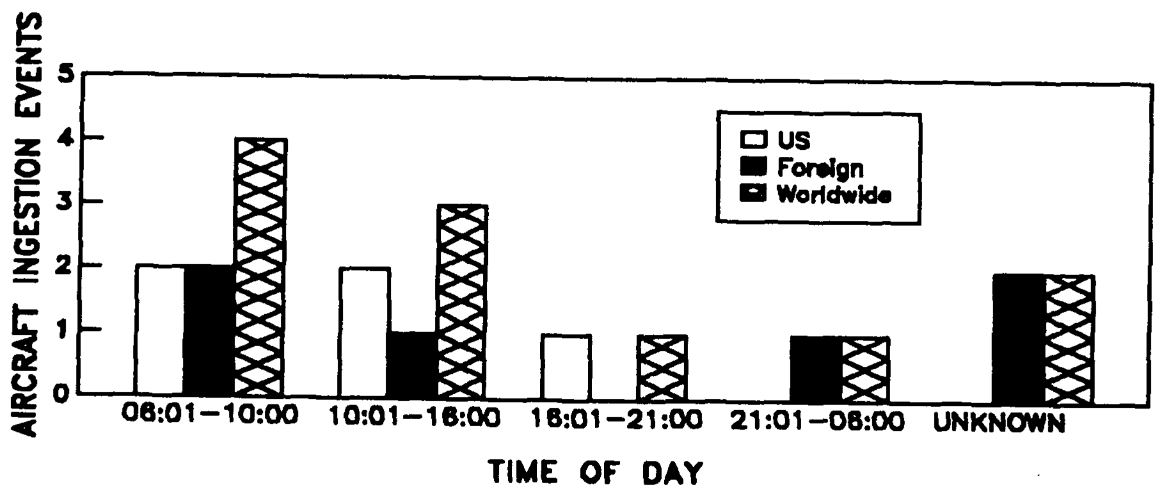


FIGURE 3.5. MULTIPLE ENGINE INGESTIONS BY TIME OF DAY

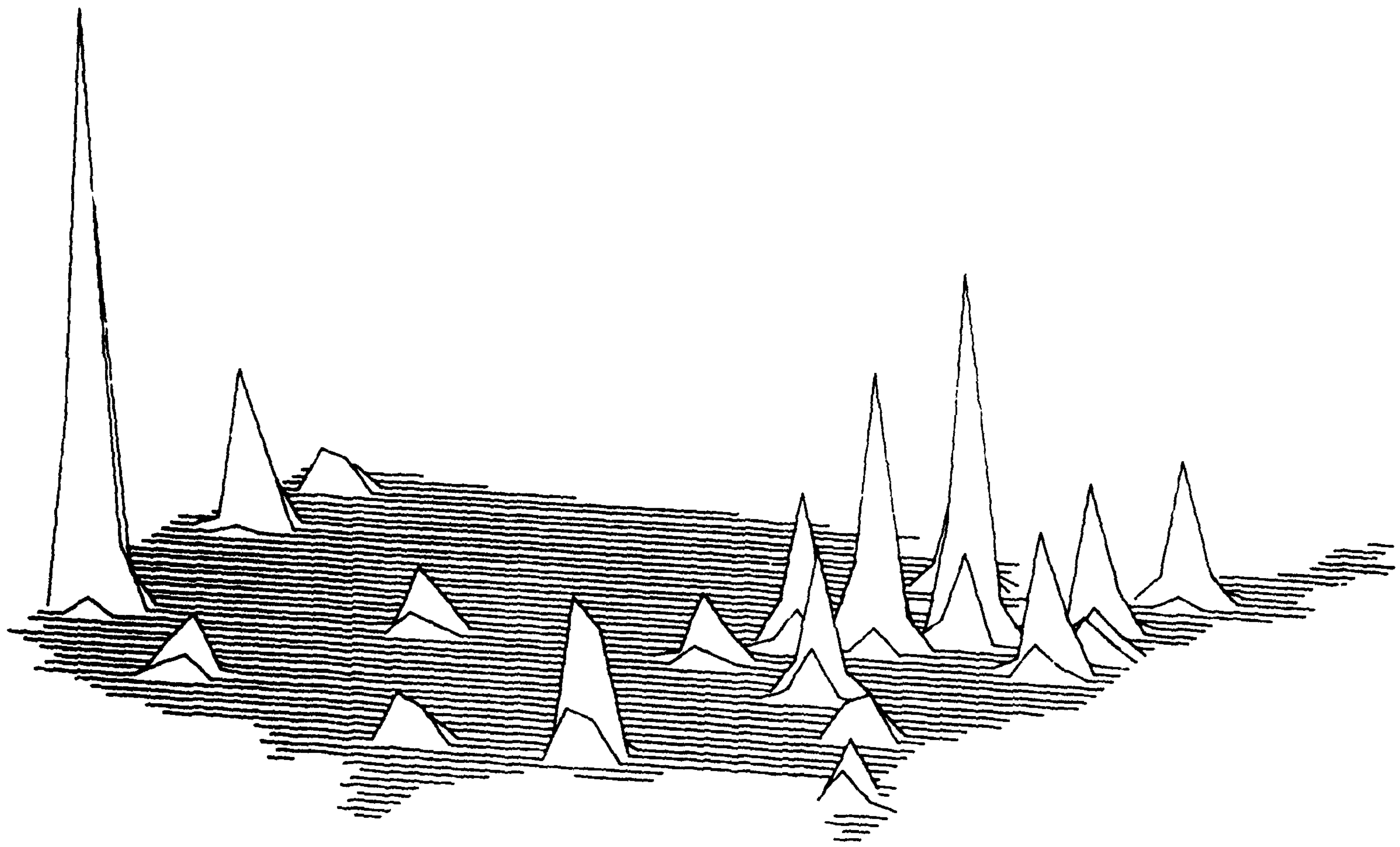

FIGURE 3.6. CONTOUR MAP OF DOMESTIC AIRCRAFT INGESTION EVENTS

## SECTION 4
## INGESTION RATES

This section describes the rates at which bird ingestions occurred during the period covered by the data. While the term "rate" usually implies occurrences per unit time, in this case it refers to occurrences per engine operation or per aircraft operation. The Poisson distribution is commonly used to describe how events are randomly distributed in time, and the bird ingestion data are shown to agree with the assumption of a Poisson process. The first part of this section provides the estimates of the basic ingestion rates. The second part describes the Poisson distribution and how it relates to the bird ingestion events. The final parts discuss statistical analysis based on the assumption that bird ingestions follow a Poisson process.

### 4.1 INGESTION RATE ESTIMATES.

This section provides a general description of ingestion rates by location, by engine, and by phase of flight. The rates are given in terms of ingestions per 10,000 engine operations and have been adjusted for differences in inlet size of the engine where appropriate. A more detailed statistical analysis of ingestion rates is presented in subsequent sections, using statistical techniques for Poisson processes.

Table 4.1 presents engine ingestion rate data for each of the four small engines. The data presented include number of ingestions, rate per 10K operations, rate per 10K operations normalized to a 10-square-foot inlet area, and rate per 10K operations normalized to a 1-foot engine diameter. The Aerospace Industries Association (AIA) uses the inlet throat dimension in analyses involving engines. The analysis of engine dimension will therefore use throat dimension. A discussion of inlet area and inlet diameter effects on ingestion rates is given in Sections 4.4 and 4.5. These rates were calculated using the reported and estimated data on operations presented earlier in this report.

Table 4.2 presents data on engine ingestion events and rates by phase of flight for all engines and for each engine separately. The 95 percent Upper Confidence Bound on Ingestions per 10,000 operations is also given (e.g., the bounds are 95 percent likely to contain the true value, allowing for sampling fluctuation). Overall, most ingestion events occurred during takeoff, followed by the landing and approach phases. Note that those ingestion events not specifically identified with a phase of flight were allocated across phases in the same proportions as the identified ingestion events. For the individual engines, the same pattern holds generally, with the exception of the ALF502 which had seven more ingestion incidents during landing than during takeoff. Overall it appears that the takeoff phase poses the highest risk from the standpoint of rate of bird ingestions. Note that because of the small sample size, some phases of flight were not represented among the ingestion events.

TABLE 4.1. ENGINE INGESTION RATES

| | ALF502 | TFE731 | TPE331 | JT15D | Total |
|---|---|---|---|---|---|
| **Engine Ingestion Events** | | | | | |
| US | 34 | 37 | 42 | 6 | 119 |
| Foreign | 29 | 34 | 23 | 4 | 90 |
| Worldwide | 63 | 72[1] | 65 | 10 | 210 |
| **Engine Hours** | | | | | |
| US | 1032101 | 3241242 | 5903575 | | |
| Foreign | 430439 | 1211003 | 2574357 | | |
| Worldwide | 1462540 | 4452245 | 8477932 | 872510 | 15264327 |
| **Engine Ingestion Events/10K Engine Hours** | | | | | |
| US | 0.329 | 0.114 | 0.071 | | |
| Foreign | 0.674 | 0.281 | 0.089 | | |
| Worldwide | 0.431 | 0.162 | 0.077 | 0.115 | 0.138 |
| **Engine Operations** | | | | | |
| US | 1187981 | 2592274 | 7084288 | | 10864543 |
| Foreign | 415354 | 968802 | 3089229 | | 4473385 |
| Worldwide | 1603335 | 3561076 | 10173517 | 785259 | 16123187 |
| **Engine Ingestion Events 10K Engine Operations** | | | | | |
| US | 0.286 | 0.143 | 0.059 | | |
| Foreign | 0.698 | 0.351 | 0.074 | | |
| Worldwide | 0.393 | 0.202 | 0.064 | 0.127 | 0.130 |
| **Inlet Area (in units of 10 square feet)** | | | | | |
| | 0.683 | 0.3125 | 0.051 | 0.215 | |
| **Engine Ingestion Events/10K ops/10 sq. ft. Inlet Area** | | | | | |
| US | 0.419 | 0.457 | 1.162 | | |
| Foreign | 1.022 | 1.123 | 1.460 | | |
| Worldwide | 0.575 | 0.647 | 1.253 | 0.592 | 0.725 |
| Worldwide (turbofans only) | | | | | 0.610 |
| **Inlet Diameter (ft.)** | | | | | |
| | 2.949 | 1.995 | | 1.655 | |
| **Engine Ingestion Events/10K ops/ft. inlet diam. (turbofans only)** | | | | | |
| US | 0.097 | 0.072 | | | |
| Foreign | 0.237 | 0.176 | | | |
| Worldwide | 0.133 | 0.101 | | 0.077 | 0.110 |

Note: One operation incident not identified as to location; included here in total but not in specific location.

TABLE 4.2. ENGINE INGESTION EVENTS AND RATES BY PHASE OF FLIGHT

| | Engine Ingestion Events | Events per 10K Operations | 95% Upper Bound | Events per 10K Operations per 10 sq. ft. Inlet Area |
|---|---|---|---|---|
| ALF502 | | | | |
| Approach | 9 | 0.056 | 0.098 | 0.082 |
| Climb | 0 | 0.000 | 0.019 | 0.000 |
| Cruise | 0 | 0.000 | 0.019 | 0.000 |
| Landing | 28 | 0.175 | 0.239 | 0.256 |
| Takeoff | 22 | 0.137 | 0.196 | 0.201 |
| Taxi | 4 | 0.025 | 0.057 | 0.037 |
| TFE731 | | | | |
| Approach | 12 | 0.034 | 0.055 | 0.108 |
| Climb | 4 | 0.011 | 0.026 | 0.036 |
| Cruise | 1 | 0.003 | 0.013 | 0.009 |
| Landing | 15 | 0.042 | 0.065 | 0.135 |
| Takeoff | 38 | 0.107 | 0.140 | 0.341 |
| Taxi | 1 | 0.003 | 0.013 | 0.009 |
| JT15D | | | | |
| Approach | 2 | 0.025 | 0.080 | 0.118 |
| Climb | 1 | 0.013 | 0.060 | 0.059 |
| Cruise | 2 | 0.025 | 0.080 | 0.118 |
| Landing | 0 | 0.000 | 0.038 | 0.000 |
| Takeoff | 5 | 0.064 | 0.134 | 0.296 |
| Taxi | 0 | 0.000 | 0.038 | 0.000 |
| TPE331 | | | | |
| Approach | 22 | 0.022 | 0.031 | 0.424 |
| Climb | 4 | 0.004 | 0.009 | 0.077 |
| Cruise | 1 | 0.001 | 0.005 | 0.019 |
| Landing | 12 | 0.012 | 0.019 | 0.231 |
| Takeoff | 26 | 0.026 | 0.035 | 0.501 |
| Taxi | 0 | 0.000 | 0.003 | 0.000 |
| ALL ENGINES | | | | |
| Approach | 45 | 0.028 | 0.036 | |
| Climb | 9 | 0.006 | 0.010 | |
| Cruise | 4 | 0.002 | 0.006 | |
| Landing | 55 | 0.034 | 0.043 | |
| Takeoff | 91 | 0.056 | 0.067 | |
| Taxi | 5 | 0.003 | 0.007 | |

This pattern is commonly found in birdstrike and bird ingestion studies. It arises from the fact that airports are typically located in desirable bird environs (vacant land, often near bodies of water). Since the birds congregate around airports there is a greater chance of striking or ingesting a bird during the phases of flight that take place close to the airports. An additional factor contributing to higher ingestion rates in the flight phases close to the ground is the fact that civilian aircraft usually cruise at altitudes well above bird flight routes.

## 4.2 THE POISSON PROCESS.

The Poisson process is the simplest type of stochastic process that describes how events are distributed in time. The Poisson process is here taken to govern ingestion events, and the times at which these events occur are random. In a Poisson process, the events are distributed somewhat evenly in time so it appears that the times at which the events occurred form a uniform distribution. This section describes some of the properties of Poisson processes that will be useful in describing bird ingestions and in testing hypotheses about bird ingestion rates.

The basis of a Poisson process is a description of the probability distribution of the number of events that occur in a given time interval. The formula for the probability of n events in an interval of length T is:

$$P(X(T) = n) = \frac{e^{-\lambda T} (\lambda T)^n}{n!} \qquad (4.1)$$

In this equation, the parameter $\lambda$ is the mean rate at which events occur. Therefore the mean number of events in the time interval of length T is $\lambda T$. Since hours of operation are not a significant measure of exposure to birdstrikes (the entire cruise portion of the flight is usually at altitudes above those at which birds are found), the time scale used will be number of engine operations rather than hours. Ingestion rates are typically reported in events per 10,000 operations which implies the use of operations as the time scale in a Poisson process.

One way in which the formula for the Poisson distribution can be derived is as the limiting distribution of the binomial distribution for large sample sizes. If the probability of a bird ingestion is the same from flight to flight then the number of ingestions in a large number of flights has a binomial distribution. If the probability of ingestion is p and the number of flights is N then the probability that n ingestions occur in the N flights is:

$$P(X(N) = n) = \begin{bmatrix} N \\ n \end{bmatrix} p^n \; (1-p) \left(N-n\right) \qquad (4.2)$$

The binomial probabilities in equation 4.2 can be approximated by a Poisson distribution with mean Np for large values of N. That is, the single flight probability of an ingestion, p, replaces $\lambda$ in equation 4.1. Past studies [references 5,6] of birdstrikes have used the hypothesis that the probability of a birdstrike is proportional to the cross sectional area of the aircraft. Applying the same hypothesis to engines implies that the bird ingestion rate should be proportional to the cross sectional area of the engine.

The inlet area effect can be incorporated into the Poisson process model by letting the parameter $\lambda$ represent the ingestion rate per unit area. The probability of n ingestions in N operations for an engine with inlet area A is:

$$P(X(N) = n) = \frac{e^{-\lambda AN} (\lambda AN)^n}{n!} \qquad (4.3)$$

The hypothesis that ingestion rates should be proportional to engine cross section area assumes that birds take no evasive action when approached by an aircraft. That is, the hypothesis assumes that the engine goes through a flock of birds like a cookie-cutter. In reality, birds tuck their wings and drop when they perceive a threat. Hence the critical engine dimension may be engine diameter (vertical height), not cross section area. In that case, the probability of n ingestions in N operations for an engine with engine diameter D is:

$$P(X(N) = n) = \frac{e^{-\lambda DN} (\lambda DN)^n}{n!} \qquad (4.4)$$

4.3 VALIDITY OF THE POISSON PROCESS MODEL FOR BIRD INGESTION.

The applicability of the Poisson process model can be tested by analyzing the times between ingestions. The interarrival times in a Poisson process are random variables that have independent exponential distributions and the mean time between arrivals is the reciprocal of the ingestion rate. The validity of the Poisson process model can be tested by applying a goodness of fit (GOF) test for the exponential distribution to the times between ingestions.

The GOF test for the exponential distribution is a modified Kolmogorov-Smirnov (K-S) test comparing the observed cumulative distribution function (CDF) to the predicted exponential CDF based on the sample mean. The K-S test uses the test statistic D defined as the maximum vertical distance between the observed and predicted CDFs. A modification to the critical values for the test statistic is required when the predicted CDF is derived from the mean of the sample. The critical values for the modified K-S test were computed by Lilliefors [reference 7]. He presents tables of critical values for sample sizes up to 30, and formulas for approximating the critical values for larger sample sizes.

Because of the small sample size, ingestions for all engines were treated together. A visual comparison of the observed versus theoretical CDFs is presented in figure 4.1. The actual value of D obtained from the observed and theoretical CDFs was 0.065, while the critical value for a probability of 0.01 is 0.133. Hence the hypothesis of an exponential distribution for interarrival times cannot be rejected at the 0.01 level of significance. The use of a Poisson process to model bird ingestions is appropriate based on the results of this test.

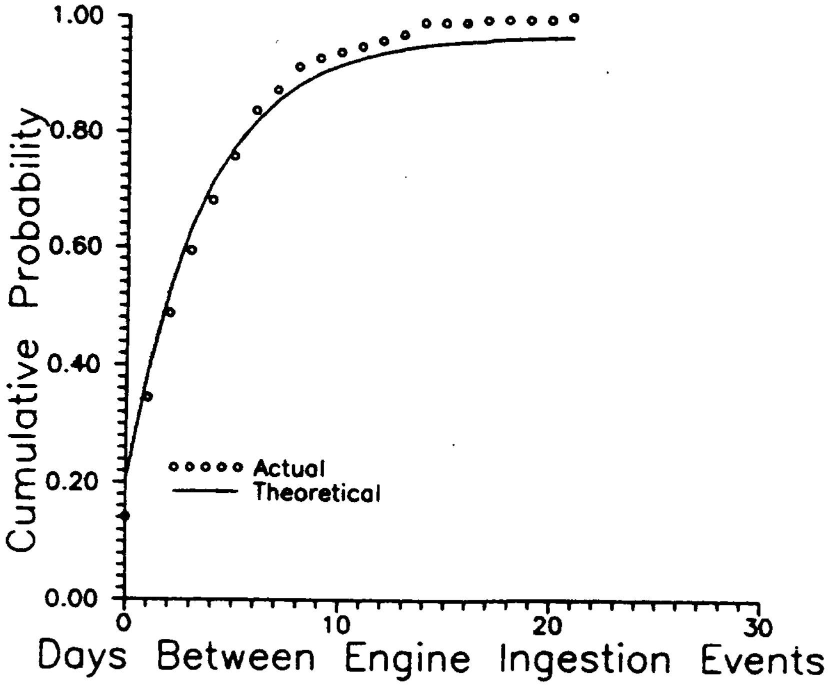


FIGURE 4.1. COMPARISON OF ACTUAL AND THEORETICAL CUMULATIVE DISTRIBUTIONS

## 4.4 INLET THROAT AREA EFFECT ON INGESTION RATES.

One property of the Poisson process model described in equation 4.3 is that ingestion rates should be proportional to the inlet area of the engine. (Physically, this can be thought of as relating ingestions to the volume swept out by the engine during a flight.) The dimension effect can be investigated for the sample of small engines by comparing actual ingestions with those predicted on the assumption that ingestions will be proportional to both number of operations and inlet throat area.

Because of the difficulty of comparing the inlet throat area for a turboprop engine with the area for a turbofan engine, only turbofan engines are included in this analysis.

The ingestion rate for all turbofan engines in this study is 0.610 engine ingestions/10K operations/10 square ft. inlet area. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-square test is applied to these expected ingestions, the value 0.47 is obtained. The critical value of chi-square for 2 degrees of freedom and probability 0.01 is 9.21. Hence the evidence is strong that the hypothesis of ingestion rate being proportional to engine inlet throat area cannot be rejected.

## 4.5 INLET THROAT DIAMETER EFFECT ON INGESTION RATES.

As noted above, it may be the case that engine ingestion events are related to engine inlet throat diameter rather than inlet throat area. Under the area hypothesis, an engine of twice the diameter would be expected to ingest four times as many birds. Under the diameter hypothesis, an engine of twice the diameter would be expected to ingest only twice as many birds. The results of testing the diameter hypothesis are presented here.

Because of the difficulty of defining an engine diameter for turboprop engines, where the inlet is wrapped around the propeller spinner, only turbofan engines are included in this analysis. For the turbofan engines, diameter is computed from the published area and an assumed circular cross section.

The ingestion rate for all turbofan engines in this study is 0.110 per ten thousand operations per foot of engine inlet throat diameter. This rate can be used to compute an expected number of ingestions for each of the individual engines. When a chi-square test is applied to these expected ingestions, the value 4.10 is obtained. By chance, the value 9.21 would be exceeded 1 percent of the time. Thus, strictly speaking, we cannot reject the hypothesis of ingestion rate being proportional to engine inlet throat diameter. However, the evidence for this hypothesis is much weaker than the evidence for ingestions being proportional to engine inlet throat area.

# SECTION 5
# ENGINE DAMAGE DESCRIPTION

Knowledge of the type of damage imposed by a well defined bird ingestion threat is useful in refining bird certification criteria that could lead to improved engine design. This section describes the information available on engine damage. The first part of this section provides descriptions of the types of damage incurred during the period covered by the data and the relationships between engine damage and bird weight, engine damage and phase of flight, engine damage and aircraft airspeed, engine damage and multiple engine and multiple bird involvement. The second part describes the statistical analysis of the relationship between bird weight and the likelihood of damage occurring in an ingestion. The third part describes any unusual crew actions taken as a result of the ingestions. The fourth part describes the engine failures that were due to bird ingestions.

## 5.1 ENGINE DAMAGE DESCRIPTION.

The types of damage that were identified in the data base were grouped into 14 categories which are defined in table 5.1. During the 2-year data collection period, nine of the damage categories occurred. Tabulations of the occurrences of combinations of damage categories for turbofan engines are presented in table 5.2. The triangular top portion of the table provides tallies of co-occurrences for all pairs of damage categories. The number in the top portion of the table represents the number of events in which both the row damage and the column damage occurred. The events in which more than two types of damage occurred were included in the tallies of the top portion of table 5.2, but they were not specifically identified as involving more than two types of damage. The first row of the bottom two rows of table 5.2 indicates the number of times each damage category was the only damage sustained from a bird ingestion. The second presents the number of times each damage category occurred either as the sole damage or in combination with any other damage category

TABLE 5.1. DEFINITION OF ENGINE DAMAGE CATEGORIES

| DAMAGE CATEGORY | SEVERITY LEVEL | DAMAGE DEFINITION |
|---|---|---|
| TRVSFRAC | Severe | Transverse fracture - fan blade broken chordwise (across) and piece liberated (includes secondary hard object damage) |
| CORE | Severe | Bent/broken compressor blades/vanes, blade/vane clash, blocked/disrupted airflow in low, intermediate, and high pressure compressors. |
| FLANGE | Severe | Flange separations. |
| TURBINE | Severe | Turbine damage. |
| BE/DE>3 | Moderate | More than three fan blades bent or dented. |
| TORN>3 | Moderate | More than three torn fan blades. |
| BROKEN | Moderate | Broken fan blades, leading edge and/or tip pieces missing, other blades also dented. |
| SPINNER | Moderate | Dented, broken, or cracked spinner (includes spinner cap). |
| RELEASED | Moderate | Released (walked) fan blades (blade retention mechanism broken). |
| TORN<3 | Mild | Three or fewer torn fan blades. |
| SHINGLED | Mild | Shingled (twisted) fan blades. |
| NACELLE | Mild | Dents and/or punctures to the engine enclosure (includes cowl). |
| LEAD_EDG | Mild | Leading edge distortion/curl. |
| BEN/DEN | Mild | One to three fan blades bent or dented. |

TABLE 5.2. TURBOFAN ENGINE DAMAGE CAUSED BY BIRD INGESTIONS

| | LEAD_EDG | BEN/DEN | BE/DE>3 | TORN<3 | BROKEN | SHINGLED | TRVSFRAC | CORE |
|---|---|---|---|---|---|---|---|---|
| BEN/DEN | 2 | | | | | | | |
| BE/DE>3 | 1 | 0 | | | | | | |
| TORN<3 | 1 | 1 | 0 | | | | | |
| BROKEN | 0 | 0 | 3 | 0 | | | | |
| SHINGLED | 0 | 3 | 2 | 0 | 0 | | | |
| TRVSFRAC | 0 | 0 | 0 | 0 | 1 | 0 | | |
| CORE | 2 | 3 | 8 | 1 | 2 | 1 | 1 | |
| NACELLE | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |

| | LEAD_EDG | BEN/DEN | BE/DE>3 | TORN<3 | BROKEN | SHINGLED | TRVSFRAC | CORE | NACELLE |
|---|---|---|---|---|---|---|---|---|---|
| ONLY DAMAGE | 1 | 10 | 16 | 1 | 3 | 0 | 0 | 7 | 2 |
| TOTAL | 6 | 18 | 27 | 3 | 7 | 5 | 1 | 21 | 4 |

The amount of data available is not sufficient to make any strong statements about correlations between types of damage. From the lower portion of the table, it can be seen that with the exception of "shingled" and "broken," when a given type of damage occurred, in half or more of the cases it was the only type which occurred (i.e., conditional probability of no other damage exceeds 0.50). "Broken" appeared by itself in only three of seven cases, or slightly less than half; shingled never occurred by itself, but always in conjunction with other kinds of damage.

The TPE331 turboprop engines did not experience any multiple damage category events. Since turboprop engines have no fan stage and no bypass airflow, a bird that is ingested goes directly into the engine core: For this reason the damage that occurred was almost always core damage. Damage to the engine core occurred in 30 events and to the engine nacelle in 1 event. No further specific damage categories were indicated for the TPE331 turboprop engine. A further description of the damage that occurred may be available in the remarks column of the bird ingestion data base (see appendix B) on an individual event basis. It should be noted that in many of the turboprop engine ingestions a blockage of airflow (i.e., primary fuel nozzle/combustor dome flow area, secondary combustion liner diffusion zones) occurred due to the bird debris and there was minor or no physical engine damage.

Tables 5.3 and 5.4 attempt to establish a relationship between the weight of the ingested bird and the resulting engine damage. Table 5.3 shows the number of engine ingestion events with and without reported damage in each specified bird weight range. The damage summaries in table 5.4 for turbofan engines and table 5.5 for turboprop engines were made by tallying the damage codes from the events shown in table 5.3 in each specified bird weight range.

Since many of the engine ingestion events have multiple damage categories, the total number of damage categories does not equal the number of engine ingestion events. Tables 5.4 and 5.5 also show the damage sustained by those engines that were considered to have failed due to the bird ingestion. See Section 5.4 for more information on engine failure.

The amount of data available is insufficient to draw any correlations between the weight of the ingested bird and the type of damage that occurs. However, tables 5.4 and 5.5 show that the majority of the ingestions (31) in which the bird weighed less than or equal to 8 ounces caused no damage. In comparison, all of the birds ingested that weighed more than 24 ounces caused some engine damage.

The relationship between engine damage, phase of flight, and aircraft airspeed is shown in tables 5.6 and 5.7. Table 5.6 depicts the relationship between engine damage and phase of flight. Of the 156 known phase-of-flight engine ingestion events, 48 percent occurred on takeoff and climb and 5 percent of the engine ingestion events that took place during takeoff and climb resulted in engine damage; in comparison, only 47 percent resulted in damage during approach and landing. This appears to establish a relationship between engine speed (thrust) and bird ingestion engine damage since engine speed would typically be higher during takeoff and climb than during approach and landing. It should be noted that the number of engine failures that occurred during takeoff and climb were only one greater than the engine failures that occurred during approach and landing.

TABLE 5.3. TALLY OF POSITIVELY INDENTIFIED BIRD SPECIES BY WEIGHT RANGE AND ENGINE TYPE

| Weight Range (oz.) | Bird Indentifications* Turbofan | Turboprop |
|---|---|---|
| $0 < x \leq 8$ | 41 | 7 |
| $8 < x \leq 16$ | 13 | 2 |
| $16 < x \leq 24$ | 4 | 1 |
| $24 < x \leq 32$ | 0 | 1 |
| $32 < x \leq 40$ | 1 | 2 |
| $x > 40$ | 6 | 0 |
| Totals | 65 | 13 |

*One counted for each engine ingestion event

TABLE 5.4. BIRD INGESTION TURBOFAN DAMAGE SUMMARY

| Severity | Damage Category | Bird Weight Range (oz.) | | | | | |
|---|---|---|---|---|---|---|---|
| | | $(0 < x \leq 8)$ | $(8 < x \leq 16)$ | $(16 < x \leq 24)$ | $(24 < x \leq 32)$ | $(32 < x \leq 40)$ | $(x > 40)$ |
| | None | 27 | 5 | 1 | 0 | 0 | 0 |
| | Damage Unknown | 1 | 1 | 0 | 0 | 0 | 0 |
| | Other | 3/1* | 4 | 0 | 0 | 0 | 0 |
| Mild | | | | | | | |
| | Lead-Edg | 0 | 2 | 0 | 0 | 1 | 1/1* |
| | Shingled | 1 | 0 | 1 | 0 | 0 | 1 |
| | Ben/Den | 6/1* | 3 | 0 | 0 | 0 | 1/1* |
| | Torn 3 | 1 | 0 | 0 | 0 | 1 | 1/1* |
| | Nacelle | 1 | 1 | 1 | 0 | 0 | 1 |
| Moderate | | | | | | | |
| | Be/De $>$ 3 | 3 | 2 | 3 | 0 | 0 | 3/2* |
| | Torn $>$ 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Broken | 0 | 0 | 0 | 0 | 0 | 2/2* |
| | Spinner | 0 | 0 | 0 | 0 | 0 | 0 |
| | Released | 0 | 0 | 0 | 0 | 0 | 0 |
| Severe | | | | | | | |
| | Trvs Frac | 0 | 0 | 0 | 0 | 0 | 1/1* |
| | Core | 3 | 3 | 0 | 0 | 0 | 6/4* |
| | Flange | 0 | 0 | 0 | 0 | 0 | 0 |
| | Turbine | 0 | 0 | 0 | 0 | 0 | 0 |

*Number of occurrences/number of occurrences when engine failed

TABLE 5.5. BIRD INGESTION TURBOPROP DAMAGE SUMMARY

| Damage Category | Bird Weight Range (oz.) | | | | | |
|---|---|---|---|---|---|---|
| | $(0 < x \leq 8)$ | $(8 < x \leq 16)$ | $(16 < x \leq 24)$ | $(24 < x \leq 32)$ | $(32 < x \leq 40)$ | $(x > 40)$ |
| None | 4 | 1 | 1 | 0 | 0 | 0 |
| Damage Unknown | 1 | 0 | 0 | 0 | 1 | 0 |
| Other | 0 | 0 | 0 | 0 | 1 | 0 |
| Lead-Edg | 0 | 0 | 0 | 0 | 0 | 0 |
| Shingled | 0 | 0 | 0 | 0 | 0 | 0 |
| Ben/Den | 0 | 0 | 0 | 0 | 0 | 0 |
| Torn < 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nacelle | 0 | 0 | 0 | 0 | 0 | 0 |
| Be/De > 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Torn > 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Broken | 0 | 0 | 0 | 0 | 0 | 0 |
| Spinner | 0 | 0 | 0 | 0 | 0 | 0 |
| Released | 0 | 0 | 0 | 0 | 0 | 0 |
| Trvs Frac | 0 | 0 | 0 | 0 | 0 | 0 |
| Core | 2/1* | 1 | 0 | 1 | 1 | 0 |
| Flange | 0 | 0 | 0 | 0 | 0 | 0 |
| Turbine | 0 | 0 | 0 | 0 | 0 | 0 |

*Number of occurrences/number of occurrences when engine failed

TABLE 5.6. PHASE-OF-FLIGHT (POF) ANALYSIS

| | Known POF Aircraft Events/ Engine Ingestions (144/156) | Known POF Damaging Aircraft Events/ Engine Ingestions (87/92) | Known POF Engine Failure Ingestions (9) |
|---|---|---|---|
| Takeoff and Climb | 68/75 | 52/56 | 5 |
| Approaching and Landing | 65/70 | 32/33 | 4 |

TABLE 5.7. AIRCRAFT AIRSPEED ANALYSIS

| Aircraft Airspeed | Known Speed Engine Ingestions (123) | Known Speed Damaging Engine Ingestions (73) | Known Speed Damaging Engine Ingestions, Takeoff and Climb (42) | Known Speed Damaging Engine Ingestions, Landing and Approach (27) |
|---|---|---|---|---|
| $<$ 140 Knots | 87 | 50 | 30 | 18 |
| $\geq$ 140 Knots | 36 | 23 | 12 | 9 |

Table 5.7 shows the number of engine ingestion events and the number of damaging engine ingestions known to have occurred below 140 knots airspeed and at or above 140 knots. The table also shows the phase of flight that these damaging engine ingestions occurred in those airspeed ranges. There were seven percent more engine ingestions that resulted in engine damage at or above 140 knots airspeed than those that occurred below 140 knots. It is also shown that a greater number of damaging ingestions occurred during takeoff and climb than during approach and landing at both aircraft airspeed ranges.

Multiple engine and multiple bird ingestion events present the greatest safety hazard to aircraft. Table 5.8 shows the number of these events that occurred. Eleven aircraft had bird ingestions into more than one engine during the same event, and four events resulted in damage to more than one engine. There were also four events where multiple birds were ingested into more than one engine, potentially the most hazardous condition an aircraft can encounter.

Table 5.8 also gives the number of engine ingestion events where more than one bird was ingested into the engine. Of the 30 multiple bird engine ingestions that occurred, 77 percent of the ingestions resulted in some engine damage. In comparison, only 46 percent of the engines that ingested a single bird resulted in some engine damage. Ten percent of the multiple bird ingestions resulted in engine failures compared to only four percent of the single bird ingestions.

## 5.2 PROBABILITY OF DAMAGE.

One of the key questions which inspired the bird ingestion survey is the issue of what weight bird should be simulated in certification testing. Two of the main issues in deciding what the certification bird weight should be are (1) the likelihood of ingesting a bird of that weight or heavier and (2) the likelihood that damage will result from ingesting a bird of the certification weight. The issue of bird weights is discussed in Sections 3 and 7 while the probability of damage is the topic of this section.

In general, the heavier the bird ingested, the greater the engine damage. However, the problem of relating bird weight to engine damage is made more complicated by the fact that in a few cases small birds caused considerable engine damage, while in other cases large birds were ingested with no engine damage. Figure 5.1 illustrates the variation in damage for turbofan engines. For the lowest weight range, there was one case of severe damage and two cases of mild or unspecified damage. All other ingestions resulted in no reported damage. With increasing bird weight, the proportion of ingestion events resulting in severe damage increased, as did the proportion of ingestion events resulting in mild or moderate damage. In the heaviest weight range, there were only four ingestion events (out of 21 total for this weight range) which resulted in no damage.

For the turboprop engine, the situation is somewhat different because of damage definitions that are different from those used for turbofans. Regardless of bird weight, there were no instances of damage being classified as more severe than mild. In 11 ingestion events, including 5 in the highest weight range, damage was limited to mild. There was one ingestion event in the highest weight range which resulted in no damage.

TABLE 5.8. MULTIPLE ENGINE AND MULTIPLE BIRD ANALYSIS

| | Aircraft Events/ Engine Ingestions | Damaging Engine Ingestions | Engine Failure Ingestions |
|---|---|---|---|
| Multiple Engine | 11/23 | 12/4* | 0 |
| Multiple Bird | 26/30 | 23 | 3 |
| Single Bird | 175/180 | 83 | 7 |

*Aircraft events where more than one engine damaged

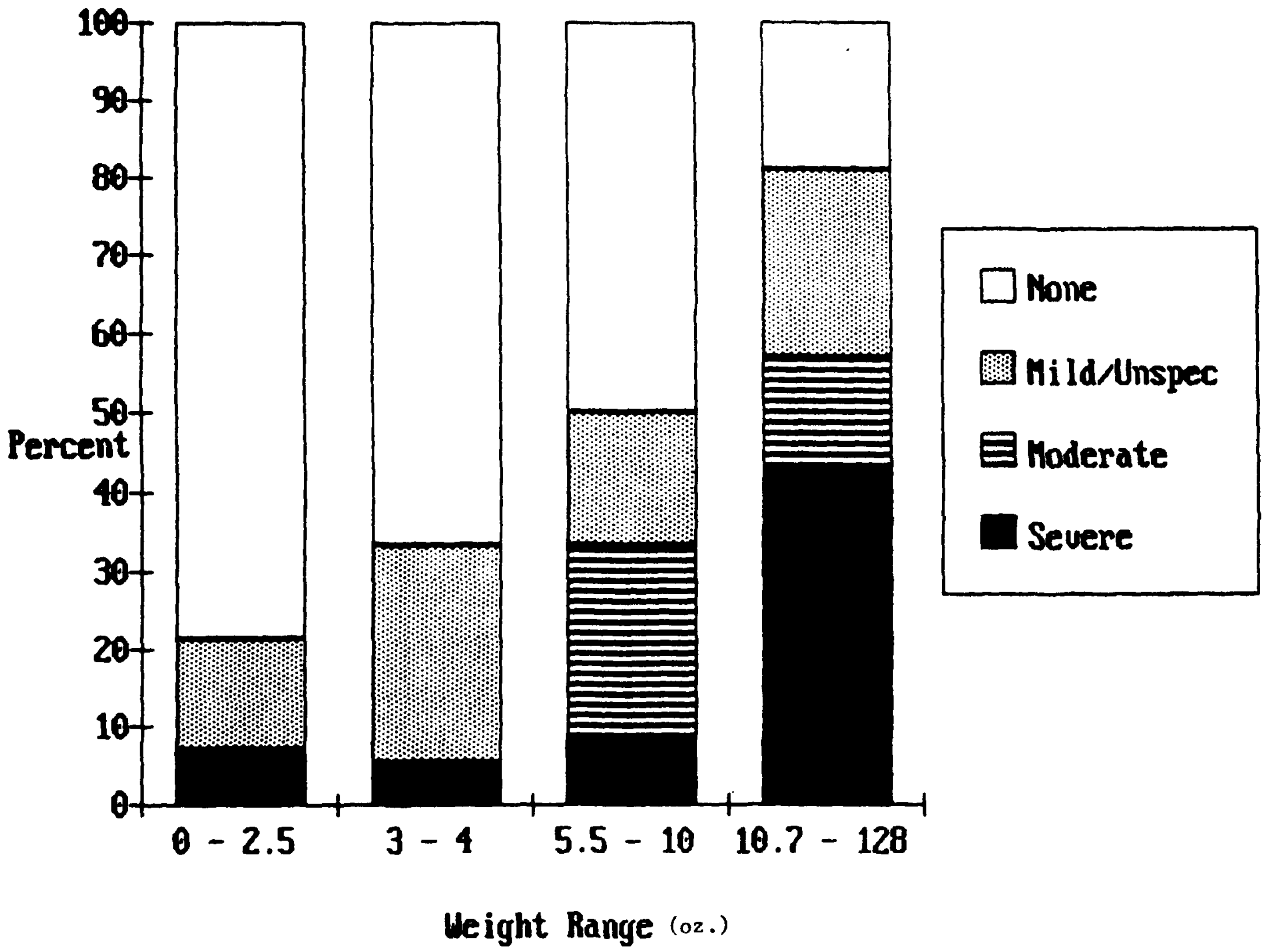


FIGURE 5.1. SERVERITY OF DAMAGE FOR TURBOFAN ENGINES VERSUS BIRD WEIGHT RANGE

This situation is similar to bioassay experiments, in which a continuous variable (dose size) produces a discontinuous result (cure/no cure, cancer/no cancer, etc.). In such experiments, it is usually found that a small dose produces the effect in a few experimental subjects, while a large dose produces the effect in many subjects. It would be more convenient, of course, if there were a threshold dose such that below the threshold, no experimental subjects showed any effect, while above the threshold all experimental subjects showed the effect. Since there is no such unique threshold, the bioassay experiments are then analyzed in terms of the probability that a given dose size will produce the response.

We have chosen to use the same method of analysis for the bird ingestion data because it has the same characteristics as bioassay data: a small "dose" may cause damage, but the likelihood of damage is greater with larger "doses." Our approach is to compute the probability of damage (POD) as a function of bird weight. The key elements are that the probability of success for a Bernoulli trial is related to a continuous stimulus variable. In bird ingestion, the Bernoulli trial is whether or not damage occurs and the stimulus variable is the weight of the ingested bird.

Linear logistic analysis is the most commonly used method of analyzing the dosage-response type of data. It is used not only in bioassay experiments, but in transportation studies involving choice of transportation mode. It has also been used successfully in relating the probability of transparencies breaking as a function of projectile size in dealing with the problem of propwash blown gravel breaking helicopter windshields. In that case, the transparency is sometimes broken by small stones; yet in other cases, it survives impact by large stones. Nevertheless, heavier stones have a greater probability of breaking the transparency. The logistic distribution function serves as the basis for the linear logistic analysis. There are several ways in which the logistic distribution function can be parameterized. The one we used is given by:

$$\mathrm{POD}(w) = 1/(1+\exp[-(\pi/\sqrt{3})(\ell n(w)-\mu)/\sigma]) \qquad (5.1)$$

In this parameterization, w is the bird weight, $\mu$ represents the mean logarithm of bird weight, and $\sigma$ is a parameter that is related to the steepness of the POD function. This parameterization is selected because of its similarity to the usual parameterization of the familiar Normal probability distribution. The logistic probability density is symmetrical about the mean $\mu$. Therefore $\mu$ is not only the mean, it is also the median and the mode of the distribution. In particular, it is the logarithm of the bird weight with a 50 percent chance of causing damage.

The estimation of the function given in equation 5.1 has been extensively studied, and the methods have been described in the literature (see references 8 and 9). The method of maximum likelihood provides the best estimates for the type of data in the bird ingestion study since there are only a few ingestions at each weight. The software for estimating the parameters of equation 5.1 has been developed and extensively tested at the UDRI and verified by researchers at other institutions.

The types of damage were categorized as mild, moderate, or severe by the FAA. (Actual data are presented in appendix B.) Three distinct analyses were conducted based on the severity ratings. The three analyses estimated the probability of any damage at all, the probability of at least moderate damage, and the probability of severe damage. Figures 5.2, 5.3, and 5.4 show the estimated POD functions along with confidence bounds on the POD functions for the analyses.

Figure 5.2 shows the probability of any damage occurring and includes all three severity levels as positive responses, including unspecified damage levels. The probability of any damage occurring rises steeply at first, then flattens out. There is a significant probability of damage at 20 ounces, and almost 90 percent probability of damage at 100 ounces.

Figure 5.3 shows the probability of at least moderate damage. The probability of moderate damage does not rise quite as steeply as the probability of any damage. The probability of damage reaches almost 90 percent at weights of 100 ounces.

Figure 5.4 shows the probability of severe damage. The probability of severe damage reaches about 65 percent at a weight of 100 ounces. The rise is much less steep than the two preceding curves, being almost linear.

The sample size appears to be large enough that the estimates of damage probability are reliable. Moreover, as shown in Section 3, there seems to be no relationship between severity of engine damage and the likelihood that bird weight was determined (through identification of species). Hence, there is no reason to believe that the estimates of probability of damage are biased either upward or downward from this cause.

## 5.3 CREW ACTION DESCRIPTION.

Two other factors that relate to the severity of engine damage are whether or not a crew action is required (aborted takeoff (ATO), air turnback (ATB), or diversion (DIV)) and whether or not the engine was shut down (IFSD) as a result of the ingestion. Table 5.9 presents the conditional probabilities that a crew action is required given the severity of the damage that the engine incurs [P(CA D)]. The probability that a crew action is required increases with the severity of engine damage as would be expected. The third column of table 5.9 contains the upper 95 percent confidence bound on the conditional probabilities presented in the second column.

A crew-initiated in-flight engine shutdown occurred in seven of the 210 engine ingestion events. There was one involuntary in-flight shutdown of a turbofan engine, and three involuntary in-flight shutdowns of a turboprop engine. This corresponds to an estimated conditional probability of an involuntary in-flight shutdown of 0.019 with a 95 percent confidence bound of $4.359 \times 10^{-2}$. Given the small sample size, and only 16 total instances of in-flight shutdown, no inferences can be drawn about the causes of in-flight shutdowns.

## 5.4 ENGINE FAILURE.

Engine failures are important areas to consider when analyzing these engine bird ingestion events. For the purpose of this study an engine failure was considered to have occurred when an engine was not able to produce and maintain usable thrust of at least 50 percent. A transverse fan blade fracture and an involuntary engine in-flight shutdown were considered to be engine failures in all cases. Otherwise, an engineering judgment was made based on the extent of engine damage, effect on flight, phase of flight, and any other factors that may have been provided in the description of the event or investigation summary.

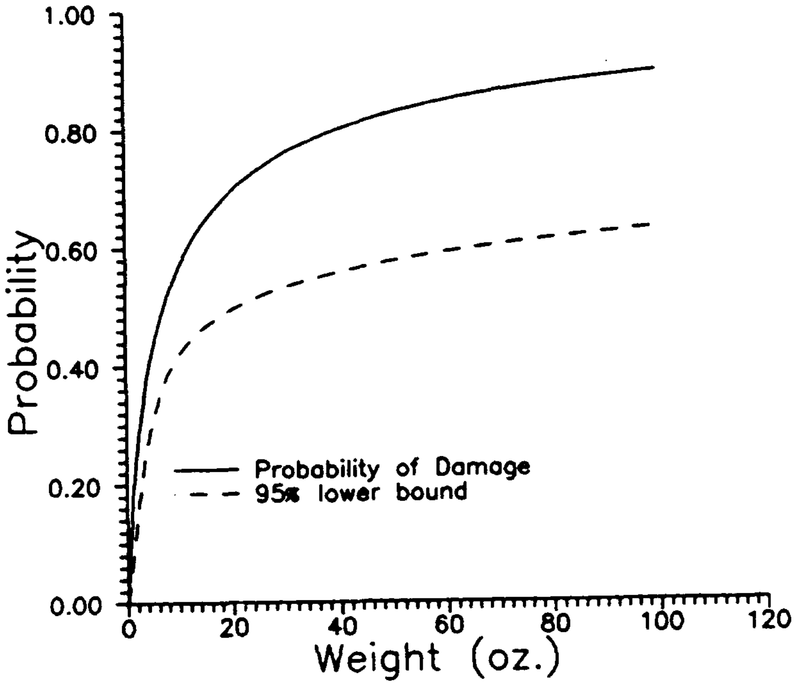


FIGURE 5.2 PROBABILITY OF ANY DAMAGE VERSUS BIRD WEIGHT

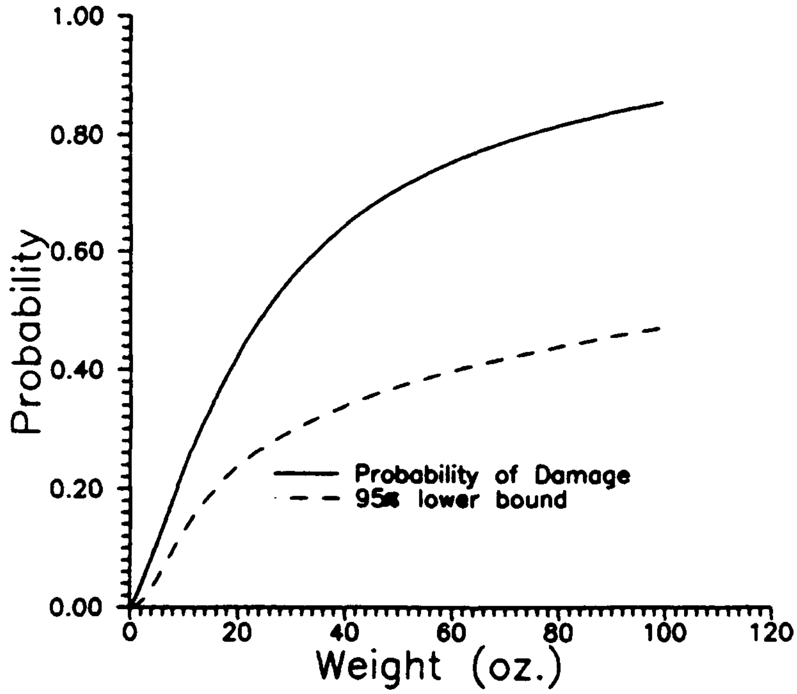


FIGURE 5.3 PROBABILITY OF AT LEAST MODERATE DAMAGE VERSUS BIRD WEIGHT

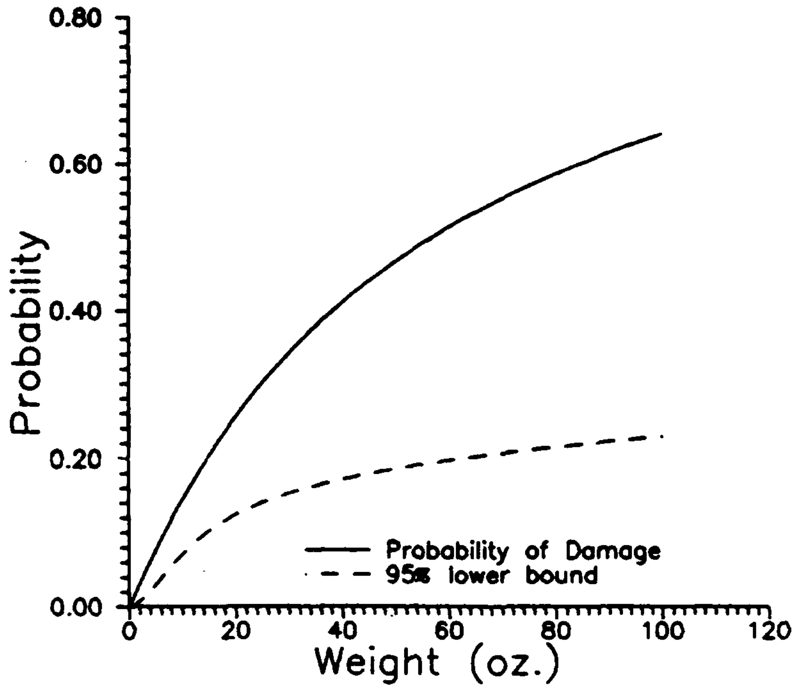


FIGURE 5.4. PROBABILITY OF SEVERE DAMAGE VERSUS BIRD WEIGHT

There were ten ingestion events which resulted in engine failure, ranging from partial power loss, through voluntary shutdown, to involuntary shutdown. The number of cases is too small for any patterns to be apparent. However, some summary is possible. Table 5.10 provides a summary of some of the important data categories for the engine ingestion events that resulted in an engine failure. Overall, five percent of the engine ingestion events resulted in an engine failure. The turbofan engine failure rate was 0.01 failures per ten thousand aircraft operations, and the turboprop engine failure rate was 0.004 failures per ten thousand aircraft operations.

Table 5.10 shows that a voluntary or involuntary in-flight shutdown of the engine occurred in eight of the ten engine failures. There was also a power loss associated with all of the engine failures where there was information reported in the power loss category. The only relationship that appears between the damage codes of these engine failures is that in all but one event there was core damage.

Reviewing the bird threat data for these engine failures shows that seven of the engine failures were caused by the ingestion of a single bird and three were caused by the ingestion of two birds. This is a much higher percentage than the fraction of all ingestion events which involved multiple birds, suggesting that engine failure is more likely in cases of multiple bird ingestion. Also, in four of the six engine failures where the bird weight was known the bird or birds weighed more than four pounds. However, the other two were caused by single birds that weighed less than 8 ounces. Comparing this with the number of engine ingestions where the bird was positively identified (table 5.3) shows that 83

TABLE 5.9. CONDITIONAL PROBABILITY OF CREW ACTION AND IN-FLIGHT SHUTDOWN GIVEN THE ENGINE DAMAGE SEVERITY

| Severity of Engine Damage | Engine Ingestion Events | Instances of Crew Action* | P(CA\|D) | Upper 95% Confidence Bound | Inflight Shutdowns | P(IFSD\|D) | Involuntary Inflight Shutdowns | P(IIFSD\|D) |
|---|---|---|---|---|---|---|---|---|
| Turbofans: | | | | | | | | |
| None | 76 | 5 | 0.066 | 0.138 | 0 | 0.000 | 0 | 0.000 |
| Any | 69 | 28 | 0.406 | 0.556 | 5 | 0.072 | 1 | 0.014 |
| Mod/Severe | 41 | 21 | 0.512 | 0.738 | 4 | 0.098 | 1 | 0.024 |
| Severe | 19 | 8 | 0.421 | 0.760 | 3 | 0.158 | 1 | 0.053 |
| Turboprop: | | | | | | | | |
| None | 25 | 4 | 0.160 | 0.366 | 2 | 0.080 | 0 | 0.000 |
| Any | 40 | 15 | 0.375 | 0.577 | 9 | 0.225 | 3 | 0.075 |
| Mod/Severe | 2 | 0 | 0.000 | 1.000 | 1 | 0.500 | 0 | 0.000 |
| Severe | 2 | 0 | 0.000 | 1.000 | 0 | 0.000 | 0 | 0.000 |

* Crew action includes Aborted Takeoff, Air Turnback, Diversion

IFSD - In flight shutdown

TABLE 5.10. ENGINE FAILURE SUMMARY BY BIRD WEIGHT

| Bird (oz.) Weight | Number of Birds | Damage Code | Phase of Flight | Power Loss | In-Flight Shutdown | Crew Action |
|---|---|---|---|---|---|---|
| 128 | 2 | A,G,I,K | Takeoff | Flame Out | Yes | ATO |
| 102 | 1 | A,D,G,K | Takeoff | Momentary | No | ATB |
| 88 | 2 | A,B,D,K | Landing | Yes | No | None |
| 64.5 | 1 | A,C,E,K | Takeoff | Compressor | Involuntary | ATB |
| 7.7 | 1 | A,K | Approach | Spool Down | Involuntary | None |
| 1.5 | 1 | A,C,P | Takeoff | ------ | Vibes | DIV |
| --- | 1 | A,D,K,P | Unknown | ------ | Yes | --- |
| --- | 1 | A,K | Approach | Flame Out | Involuntary | --- |
| --- | 1 | A,K | Approach | Spool Down | Involuntary | None |
| --- | 2 | A,K | Takeoff | 50% | Voluntary | ATB |

Note: A description of the columns and column contents can be found in appendix B.

percent of engine ingestion events, where the bird ingested weighed more than 4 pounds, resulted in engine failures, whereas only four percent of the events, where the bird ingested weighed less than 1/2 pound, resulted in engine failures.

In the six engine failure events in which weight of the ingested birds were known, the average weight was 65.3 ounces, which is much higher than either the median or the mode for ingested bird weights. That is, in cases of engine failure, the ingested bird typically was heavier than the average for all bird ingestion events. Note that the figure given above is for average weight of each ingested bird, not average ingested weight, since some of the engine failure events involved multiple ingestions. This finding is not unexpected, since a heavier bird would be expected to result in greater damage.

The failures were split almost evenly between takeoff (five engine failure events) and approach/landing (four engine failure events). (One event was not identified as to phase of flight.) For the nine engine failure events in which weather conditions are known, the sky was clear (seven cases) or had scattered clouds (two cases). This implies that weather was not a factor in engine failure.

For the nine engine failure events in which lighting conditions were known, two occurred in the dark, one at dawn, and five in light conditions. This implies that illumination was not a factor in engine failures.

The findings on weather and lighting conditions, taken together, imply that lack of visibility was not a factor in the engine failures. This is probably to be expected, since aircraft are not permitted either to land or take off in low visibility conditions, and only one of the engine failures occurred at an altitude above 1000 feet. Thus, the fact that the aircraft were flying at all would imply that visibility was acceptable at low altitude.

A final finding regarding engine failures is that in the seven of nine engine failure events in which engine location is known, the failed engine was located on the right side of the aircraft. This presents a strong contrast with the distribution of engine ingestion events where engine location is known: 98 on the right, 101 on the left, and 3 in the center. That is, for all engine ingestion events, the location is consistent with the hypothesis that engines on the left and on the right are equally likely to ingest birds. The distribution of locations for engine failures has a probability of only 0.10, and is not consistent with that hypothesis. One possible explanation is that pilots, who sit on the left, are able to see and avoid those large birds which seem to be responsible for engine failure. However, given the small number of engine failure events, this possibility is little better than pure speculation. While no convincing explanation can be offered for the discrepancy, it may be significant.

## SECTION 6
## PROBABILITY ESTIMATES

This section provides a summary of the probabilities of various engine ingestion events. The probability of an event is a measure of the likelihood that the event will occur. The probabilities in this section are calculated on a per engine operation basis and present information similar to the ingestion rates. The ingestion rates that were presented in Section 4 were calculated on the basis of 10,000 engine operations. In that section, it was shown that the ingestions did follow a Poisson distribution. As a consequence of the Poisson distribution, the ingestion rate per engine operation is equal to the probability of ingestion for a single operation. This section provides more details on the probabilities of various categories of bird ingestion events.

Table 6.1 provides the estimated probabilities and 95 percent confidence bounds for the entire small engine population for various bird ingestion events including all flight phases, multiple bird ingestions, and ingestions where the damage was moderate or severe. Note that one ingestion event was not identified as to location. Therefore the United States and foreign events do not add to the total for all phases.

The overall likelihood of a bird ingestion event in a single operation is about 1.3 in 100,000 thousand. Although this probability is very low, there are sufficient operations per year (over 1.6 million during the period covered by the data) that the expected number of ingestions is roughly 200. Most ingestions occur during takeoff or landing phases, so the probabilities for those phases are larger than for other phases of flight. Multiple bird ingestion events are comparatively rare, and this is reflected in the lower probabilities for these events.

Table 6.2 shows the probability of ingestion by bird weight range and location. This is computed by multiplying the overall probability of ingestion per operation for each of the regions (United States, foreign, worldwide) by the frequency of each bird weight range. The validity of this calculation is dependent on the randomness of bird identification. As discussed in Section 3, there appears to be no reason to believe that the probability of a bird being identified is correlated with degree of engine damage; hence, the assumption of randomness appears justified.

Table 6.3 shows the probability of an ingestion by bird weight range for each engine type and region (United States, foreign, worldwide). As with table 6.2, this is computed by multiplying the overall probability of ingestion per operation for each of the regions, computed separately for each engine type, by the frequency of each bird weight range. The same caveat applies as to randomness of bird identifications.

Table 6.4 shows the probability of ingestion by phase of flight for each engine type by region. It also shows the probability of multiple bird ingestions in the same engine, the probability of multiple engine ingestions, and the probability of moderate or severe damage. The table is computed by dividing the number of engine ingestion events in each of the conditions by the number of operations for the particular engine type in each region. Note that one ingestion for the TFE731 was not identified as to location. It is included in the world total for all flight phases but not in either United States or foreign ingestions.

TABLE 6.1. ENGINE INGESTION PROBABILITIES

| CONDITION | ENGINE INGESTION EVENTS | PROBABILITY OF INGESTION | UPPER 95% CONFIDENCE BOUND |
|---|---|---|---|
| **All Phases** | | | |
| World | 210 | 1.302E-05 | 1.460E-05 |
| US | 113 | 1.040E-05 | 1.216E-05 |
| Foreign | 86 | 1.922E-05 | 2.300E-05 |
| **Approach** | | | |
| World | 45 | 2.791E-06 | 3.578E-06 |
| US | 31 | 2.853E-06 | 3.851E-06 |
| Foreign | 12 | 2.683E-06 | 4.346E-06 |
| **Climb** | | | |
| World | 9 | 5.582E-07 | 9.741E-07 |
| US | 5 | 4.602E-07 | 9.676E-07 |
| Foreign | 3 | 6.706E-07 | 1.733E-06 |
| **Cruise** | | | |
| World | 4 | 2.481E-07 | 5.677E-07 |
| US | 1 | 9.204E-08 | 4.366E-07 |
| Foreign | 1 | 2.235E-07 | 1.060E-06 |
| **Landing** | | | |
| World | 55 | 3.411E-06 | 4.270E-06 |
| US | 24 | 2.209E-06 | 3.107E-06 |
| Foreign | 31 | 6.930E-06 | 9.353E-06 |
| **Takeoff** | | | |
| World | 91 | 5.644E-06 | 6.719E-06 |
| US | 52 | 4.786E-06 | 6.030E-06 |
| Foreign | 34 | 7.601E-06 | 1.012E-05 |
| **Taxi** | | | |
| World | 5 | 3.101E-07 | 6.520E-07 |
| US | 0 | 0 | 2.757E-07 |
| Foreign | 5 | 1.118E-06 | 2.350E-06 |
| **Multiple Birds** | | | |
| World | 30 | 1.861E-06 | 2.524E-06 |
| US | 15 | 1.381E-06 | 2.126E-06 |
| Foreign | 15 | 3.353E-06 | 5.163E-06 |
| **Moderate to Severe Damage** | | | |
| **Turbofans** | | | |
| World | 41 | 6.891E-06 | 8.941E-06 |
| US | 14 | 3.703E-06 | 5.790E-06 |
| Foreign | 23 | 1.662E-05 | 2.354E-05 |
| **Turboprops** | | | |
| World | 2 | 1.966E-07 | 6.188E-07 |
| US | 1 | 1.412E-07 | 6.696E-07 |
| Foreign | 1 | 3.237E-07 | 1.536E-06 |

Note: JT15D engine excluded in US and Foreign conditions

TABLE 6.2 PROBABILITY OF AN ENGINE INGESTION EVENT VS. BIRD WEIGHT

| Weight[1] | U.S. Events | U.S. Prob | Foreign Events | Foreign Prob | Unknown | Worldwide Events | Worldwide Prob |
|---|---|---|---|---|---|---|---|
| 0<x≤4 | 23 | 2.117E-06 | 8 | 1.788E-06 | 1 | 32 | 1.985E-06 |
| 4<x≤8 | 2 | 1.841E-07 | 7 | 1.565E-06 | 0 | 9 | 5.582E-07 |
| 8<x≤12 | 3 | 2.761E-07 | 2 | 4.471E-07 | 0 | 5 | 3.101E-07 |
| 12<x≤16 | 6 | 5.523E-07 | 4 | 8.942E-07 | 0 | 10 | 6.202E-07 |
| 16<x≤20 | 2 | 1.841E-07 | 2 | 4.471E-07 | 0 | 4 | 2.481E-07 |
| 20<x≤24 | 1 | 9.204E-08 | 0 | 0 | 0 | 1 | 6.202E-08 |
| 28<x≤32 | 1 | 9.204E-08 | 0 | 0 | 0 | 1 | 6.202E-08 |
| 32<x≤36 | 0 | 0 | 1 | 2.235E-07 | 0 | 1 | 6.202E-08 |
| 36<x≤40 | 2 | 1.841E-07 | 0 | 0 | 0 | 2 | 1.24E-07 |
| 64<x≤68 | 1 | 9.204E-08 | 0 | 0 | 0 | 1 | 6.202E-08 |
| 84<x≤88 | 2 | 1.841E-07 | 0 | 0 | 0 | 2 | 1.24E-07 |
| 100<x≤104 | 1 | 9.204E-08 | 0 | 0 | 0 | 1 | 6.202E-08 |
| 124<x≤128 | 2 | 1.841E-07 | 0 | 0 | 0 | 2 | 1.24E-07 |

[1] Ounces

TABLE 6.3. PROBABILITIES OF AN ENGINE EVENT* AS A FUNCTION OF BIRD WEIGHT, LOCATION, AND ENGINE TYPE

| | ALF502 | | | TFE731 | | | TPE331 | | | JT15D |
|---|---|---|---|---|---|---|---|---|---|---|
| | U.S. | FOREIGN | WORLDWIDE | U.S. | FOREIGN | WORLDWIDE | U.S. | FOREIGN | WORLDWIDE | WORLDWIDE |
| Engine Operations: | 1,187,981 | 415,354 | 1,603,335 | 2,592,274 | 968,802 | 3,561,077 | 7,084,288 | 3,089,229 | 10,173,518 | 785,259 |
| Bird Wt Range (Oz.) | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion | Prob. of Ingestion |
| ( 0 < X ≤ 4) | 1.010 | 0.963 | 0.998 | 0.231 | 0.413 | 0.309 | 0.071 | ... | 0.049 | ... |
| ( 4 < X ≤ 8) | ... | 0.482 | 0.125 | 0.077 | 0.310 | 0.140 | ... | 0.065 | 0.020 | ... |
| ( 8 < X ≤ 12) | 0.084 | 0.241 | 0.125 | 0.077 | 0.103 | 0.084 | ... | ... | ... | ... |
| ( 12 < X ≤ 16) | ... | ... | ... | 0.154 | 0.310 | 0.197 | 0.014 | 0.032 | 0.020 | 0.127 |
| ( 16 < X ≤ 20) | ... | 0.241 | 0.062 | 0.077 | ... | 0.056 | ... | 0.032 | 0.010 | ... |
| ( 20 < X ≤ 24) | ... | ... | ... | 0.039 | ... | 0.028 | ... | ... | ... | ... |
| ( 24 < X ≤ 28) | ... | ... | ... | ... | ... | ... | 0.014 | ... | 0.010 | ... |
| ( 32 < X ≤ 36) | ... | ... | ... | ... | ... | ... | ... | 0.032 | 0.010 | ... |
| ( 36 < X ≤ 40) | ... | ... | ... | 0.039 | ... | 0.028 | 0.014 | ... | 0.010 | ... |
| ( 64 < X ≤ 68) | 0.084 | ... | 0.062 | ... | ... | ... | ... | ... | ... | ... |
| ( 84 < X ≤ 88) | 0.084 | ... | 0.062 | 0.039 | ... | 0.028 | ... | ... | ... | ... |
| (100 < X ≤ 104) | ... | ... | ... | 0.039 | ... | 0.028 | ... | ... | ... | ... |
| (124 < X ≤ 128) | ... | ... | ... | 0.077 | ... | 0.056 | ... | ... | ... | ... |
| All Events | 1.263 | 1.926 | 1.435 | 0.849 | 1.135 | 0.955 | 0.113 | 0.162 | 0.128 | 0.127 |

* Ingestion probabilities scaled by $10^6$

TABLE 6.4. ENGINE INGESTION PROBABILITIES* BY ENGINE AND LOCATION

| | ALF502 | | | | | | TFE731 | | | | | | TPE331 | | | | | | JT15D | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | U.S. | | FOREIGN | | WORLDWIDE | | U.S. | | FOREIGN | | WORLDWIDE | | U.S. | | FOREIGN | | WORLDWIDE | | WORLDWIDE | |
| Engine Operations: | 1,187,981 | | 415,354 | | 1,603,335 | | 2,592,274 | | 968,802 | | 3,561,077 | | 7,084,288 | | 3,089,229 | | 10,173,518 | | 785,259 | |
| Condition Under Consideration | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. | Ingestion Evt | Prob. |
| All Flight Phases | 34 | 2.86 | 29 | 6.98 | 63 | 3.93 | 37 | 1.43 | 34 | 3.51 | 72 | 2.02 | 42 | 0.59 | 23 | 0.74 | 65 | 0.64 | 10 | 1.27 |
| Takeoff And Climb Phases | 15 | 1.26 | 7 | 1.69 | 22 | 1.37 | 19 | 0.73 | 23 | 2.37 | 42 | 1.18 | 23 | 0.32 | 7 | 0.23 | 30 | 0.29 | 6 | 0.76 |
| Approach And Landing Phases | 19 | 1.60 | 18 | 4.33 | 37 | 2.31 | 17 | 0.66 | 10 | 1.03 | 27 | 0.76 | 19 | 0.27 | 15 | 0.49 | 34 | 0.33 | 2 | 0.25 |
| Dual Engine - Single Bird Events | 3 | 0.25 | 0 | -- | 3 | 0.19 | 0 | -- | 1 | 0.10 | 1 | 0.03 | 0 | -- | 1 | 0.03 | 1 | 0.01 | 0 | -- |
| Multiple Birds - Single Engine Events | 1 | 0.08 | 1 | 0.24 | 2 | 0.12 | 9 | 0.35 | 4 | 0.41 | 13 | 0.37 | 2 | 0.03 | 2 | 0.06 | 4 | 0.04 | 0 | -- |
| Multiple Birds - Dual Engine Events | 1 | 0.08 | 1 | 0.24 | 2 | 0 12 | 1 | 0.04 | 2 | 0.21 | 3 | 0.08 | 0 | -- | 1 | 0.03 | 1 | 0.01 | 0 | -- |
| Moderate Or Severe Damage | 3 | 0.25 | 2 | 0.48 | 5 | 0.31 | 11 | 0.42 | 21 | 2.17 | 32 | 0.90 | 1 | 0.01 | 1 | 0.03 | 2 | 0.02 | 4 | 0.51 |

*Ingestion probabilities scaled by $10^5$

## SECTION 7
## DATA QUALITY

The interpretations derived from any large set of data are only as good as the data. The use of poor data can lead to invalid and misleading conclusions. The conclusions reached in this report should be interpreted in the context of the sources of the data and the quality of the data. The following paragraphs discuss the sources of data for the first 2 years and the quality of the data as measured by the consistency of the data collected in the first and second years.

### 7.1 DATA SOURCES.

The data used in this report were collected by the engine manufacturers and supplied to the FAA. The data were in turn supplied to the University of Dayton by the FAA. The method of data collection was a census rather than a survey sample. That is, the goal was to collect information on every bird ingestion event affecting the four engines in the study, during the 2-year period (second year only for the JT15D). A complete census is nearly impossible to achieve under any circumstances; therefore, estimates involving the total number of ingestions, such as ingestion rates, should be viewed as lower bounds. Other than the possibility that some ingestion events escaped the census, there were no known problems which systematically affected the reliability of the data.

### 7.2 INTERNAL CONSISTENCY.

The data collected during the second year should be consistent with the data collected during the first year, if the two data sets are to be combined. Hence it is necessary to compare the two data sets for consistency. This is done below, with two different tests being applied.

The first test compares the ingestion rates (ingestions per operation) for each engine for the first year and for the two years. Section 4 provided evidence that aircraft ingestion events occur according to a Poisson process so that a Z test can be used to compare the two. According to the properties of a Poisson process, the proportion of events that were recorded in the first year should be equal to the proportion of operations that were conducted in the first year.

The formula for the expected proportion of events in the first year becomes

$$P = O1/(O1 + O2) \qquad (7.1)$$

where O1 and O2 are the number of operations for a particular engine in the first and second years, respectively. The proportion of aircraft ingestion events in the first year is used as P along with P as defined above, in the equation for Z

$$Z = (P - P)/\mathrm{SQRT}(P*(1 - P)/N) \qquad (7.2)$$

where N is the total number of ingestion events for the engine.

The Z statistic defined in equation 7.2 is used to test the null hypothesis that there is no difference between the ingestion rates of a given engine between the first year and the two years taken together. Table 7.1 gives the results of the analysis. Any type of change, either increase or decrease, is important. Hence a two-sided test should be used. The critical value for a two-sided test and 5

TABLE 7.1. COMPARISON OF INGESTION RATES FOR FIRST AND SECOND YEARS

| Engine | First Year | | Both Years | | | | |
|---|---|---|---|---|---|---|---|
| | Events | Operations | Events | Operations | P | $\hat{P}$ | Z |
| U.S. | | | | | | | |
| ALF502 | 12 | 596905 | 34 | 1187981 | 0.502 | 0.353 | -1.744 |
| TFE731 | 23 | 1279280 | 37 | 2592994 | 0.493 | 0.622 | 1.559 |
| TPE331 | 19 | 3389810 | 42 | 7084288 | 0.478 | 0.452 | -0.339 |
| Foreign | | | | | | | |
| ALF502 | 14 | 125013 | 29 | 415354 | 0.301 | 0.483 | 2.134 |
| TFE731 | 17 | 471185 | 34 | 968802 | 0.486 | 0.500 | 0.159 |
| TPE331 | 14 | 1351306 | 23 | 3089229 | 0.437 | 0.609 | 1.656 |

percent significance is $\pm 1.96$. As the table shows, only one of the Z values exceeds the $\pm 1.96$ bound. Considering that we have performed six tests, each of which has probability 0.05 of falling "out of bounds" by pure chance, there is actually one chance in four that at least one of the six tests will fall out of bounds by pure chance. The fact that one test did exceed the limit cannot be considered strong evidence that the data are inconsistent from the first to the second year.

Another check on the consistency of the data collection is to compare the birds that were identified in the 2 years. There were too many different species and locations of ingestions, and too few of each species or location, to allow comparisons of those features. However, if the species identifications are reduced to bird weights, the cumulative weight distributions for the first and second years can be compared. Table 7.2 provides the cumulative bird weight distributions for the first and second years, worldwide. The data are plotted in figure 7.1 to provide a visual comparison. As can be seen from both the table and the figure, there are substantial differences between the distributions at the low end.

A statistical measure of the closeness of the cumulative distributions is the Kolmogorov-Smirnov D test. The D statistic is compared to a test value based on the sizes of the two samples. When the D statistic is smaller than the test value, the distributions are considered to be similar at a given significance level.

The maximum difference between the distributions in figure 7.1 is 0.413. For the sample sizes, this maximum difference should be less than 0.387 at a significance level of 0.01. The conclusion is that with a possible chance of error of 1 in 100, the two cumulative distributions are significantly different. Hence by this test, the data in the 2 years are not consistent.

In summary, the tests have found some significant differences between the data sets collected in the first and the second years. However, this need not be attributed to faults in data collection. It might also be due to changes in aircraft operational patterns or to changes in bird habits. The information available is not sufficient to distinguish between these alternative possibilities.

TABLE 7.2. CUMULATIVE DISTRIBUTIONS, FIRST AND SECOND YEARS

| Weight (oz) | Year 1 | Year 2 |
|---|---|---|
| 4 | 0.235 | 0.649 |
| 8 | 0.382 | 0.757 |
| 12 | 0.471 | 0.811 |
| 16 | 0.647 | 0.919 |
| 20 | 0.735 | 0.946 |
| 24 | 0.765 | 0.946 |
| 28 | 0.794 | 0.946 |
| 36 | 0.824 | 0.946 |
| 40 | 0.853 | 0.973 |
| 68 | 0.882 | 0.973 |
| 88 | 0.912 | 1 |
| 104 | 0.941 | 1 |
| 128 | 1 | 1 |

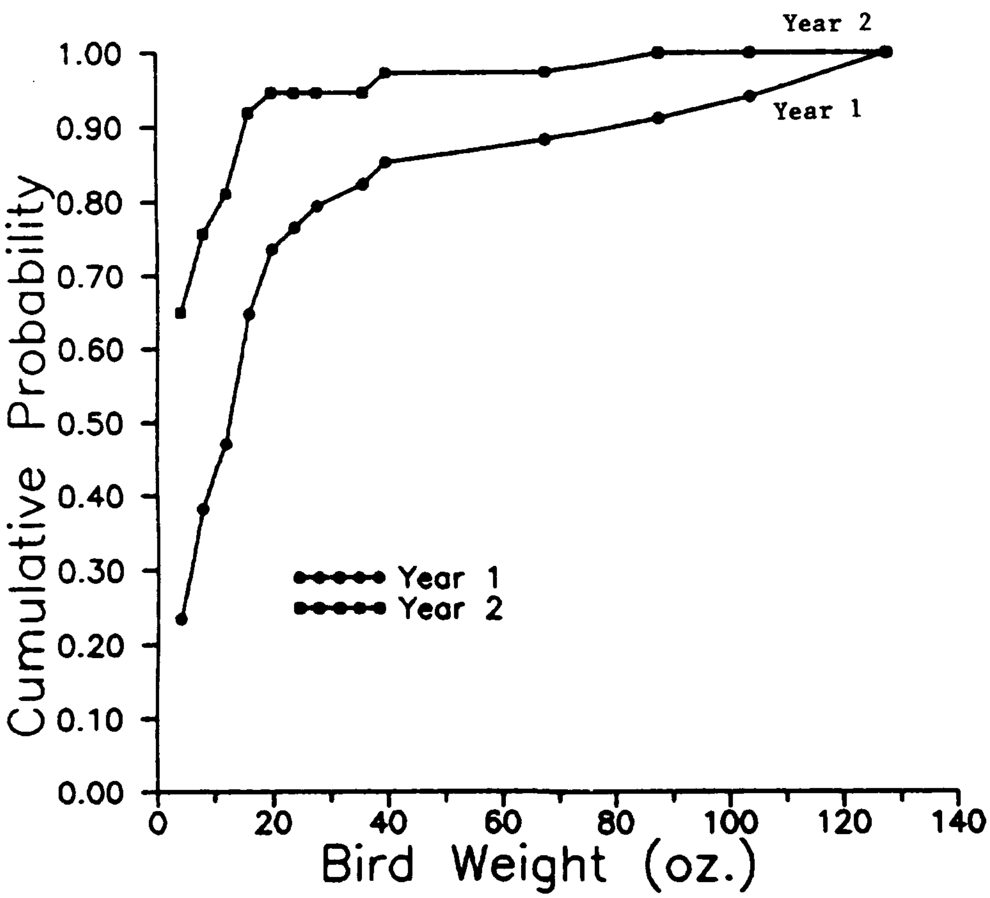


FIGURE 7.1. COMPARISON OF BIRD WEIGHT DISTRIBUTIONS, FIRST AND SECOND YEARS

# SECTION 8
# CONCLUSIONS

This section summarizes conclusions from the data collected.

## Bird Descriptions

- Gulls, doves, and lapwings are the birds most often ingested.

- Eighty-six percent of the birds that were positively identified by an ornithologist weighed less than or equal to one and a half pounds. In comparision ninety-two percent weighed less than or equal to two and a half pounds.

- Fourteen percent of the engine ingestion events are multiple bird ingestions.

- Six percent of the aircraft ingestion events are multiple engine events.

- The identification rate does not seem to vary with degree of engine damage.

- The weight of a bird most likely to be ingested outside the United States is approximately twice as heavy as one ingested within the United States.

- Ingestions are least likely to occur at night.

## Ingestion Rates

- The foreign engine bird ingestion rates are higher than the United States rates.

- Bird ingestion events can be modeled as a randomly variable Poisson process.

- Bird ingestion rates are proportional to the engine inlet throat cross section area.

- Turbofan engines had a higher ingestion rate than the turboprop engine.

## Effect on Flight

- Six percent of all aircraft ingestion events result in an aborted takeoff, fourteen percent result in an air turnback, and three percent result in an aircraft diversion to an alternate airport.

- During eight percent of the aircraft ingestion events, an in-flight shutdown of an engine occurred. During two percent, there was an involuntary in-flight engine shutdown.

- The probability that a crew action is required increases with the severity of engine damage.

## Engine Damage

- Fifty percent of all engine bird ingestions result in some engine damage. Forty-eight percent for turbofans and fifty-seven percent for turboprops.

- There does not appear to be any correlation among different types of engine damage.

- The probability of damage increases with the weight of the bird that is ingested.

- The probability of engine damage, given a bird ingestion has occurred, is greater when the ingestion occurs during the takeoff and climb phases of flight than those that occur during approach and landing.

- The probability of engine damage, given a bird ingestion has occurred, is greater when the aircraft airspeed is greater than or equal to 140 knots than those that occur at less than 140 knots.

- Five percent of all engine bird ingestions result in an engine failure.

- Two-thirds of the engine failures, where the bird weight was positively identified, involved bird weights greater than four pounds. In comparison one-third were at weights less than one-half pound.

- Engine failure appears more likely to occur when multiple birds are ingested.

- The mean or average weight (65.3 oz.) of the birds that caused engine failures was heavier than the mean (16.8 oz.) for all bird ingestion events.

- Engine failure is not necessarily associated exclusively with severe engine damage.

- A disproportionate number of engine failures occurred on the right side of the aircraft.

## Probabilities of Ingestion

- Bird ingestions are more likely during the takeoff and landing phases of aircraft operation.

## Data Quality

- There are some statistically significant differences between the data collected in year 1 and in year 2.

## SECTION 9
## REFERENCES

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## SECTION 10
## GLOSSARY OF TERMS

| Term | Definition of Term |
|---|---|
| Ingested Bird | A bird having experienced the process of bird ingestion. |
| Aircraft Operation | A nonstop aircraft flight from one airport to another (includes taxi-out from departure airport through taxi-in at arrival airport). |
| Engine Operation | The participation of each engine of an aircraft in an aircraft operation (e.g., a twin engine aircraft would, ideally, experience two engine operations for each aircraft operation). |
| Engine Ingestion Event | The simultaneous passage of one or more birds through the inlet of an engine during an engine operation. |
| Aircraft Ingestion Event | The simultaneous passage of one or more birds through the inlet of one or more engines of an aircraft during an aircraft operation. |
| Engine Hours | The total running time, measured in hours, of an engine or group of engines during a given period. |
| Ingestion Rate | Rate at which (aircraft or engine) events occur per flight event. Flight event refers to aircraft or airport operation. The components of ingestion rate are specified whenever this term is used. The influence of engine inlet opening size is not taken into account in this definition. |
| Normalized Ingestion Rate | Ingestion rate normalized to a given inlet size. Normalization allows statistical comparison of ingestion rates of engines with different inlet opening sizes. |

## APPENDIX A

## ENGINE APPLICATIONS

| Engine | Engine Type | Engine Manufacturer | Engine Face Area ($in^2$) | Typical Throat Area ($in^2$) | Typical Aircraft Installation |
|---|---|---|---|---|---|
| JT15D | Turbofan | Pratt & Whitney | 346 | 310 | Cessna Citation 1 & S2, Mitsubishi/Beech Diamond, Beechjet |
| ALF 502 | Turbofan | Textron-Lycoming | 1276 | 984 | Canadair Challenger CL-600, British Aerospace 146 |
| TFE 731 | Turbofan | Garrett | 625 | 450 | British Aerospace 125-700 & 125-800; Dassault-Breguet Falcon 10, 100, 50, and 900; Gates Learjet 35A, 55, 55ER, and 55LR; Israel Aircraft Industries Westwind 1124 and Astra 1125; Lockheed Jetstar II; Rockwell/Sabreliner 65; Cessna Citation III |
| TPE 331 | Turboprop | Garrett | 72 | 73 | Alaska F & W, Goose; British Aerospace, Jetstream 3, 31, 32; Carstedt, Jetliner 600; CASA 212; Cessna, Conquest 2; Commander 680, 690, 695, Turbocommander; Dornier 228; Fairchild Metro, Metro 2, 3, Merlin 2,3,4, Peacemaker, Porter; Grumann, S2 Tracker; Helitec s 55; IAI, S2 Tracker; Mitsubishi, Marquise, Soltaire, MU-2; Pilatus, Porter; Piper, Cheyenne 400; Short Brothers, Skyvan; Turbobeaver; Volpar, Turbo 18 |

## APPENDIX B
## CONTENTS OF FAA BIRD INGESTION DATA BASE
## SMALL ENGINES
## MAY 1987 - APRIL 1989

This appendix presents the contents of the small engine bird ingestion data base maintained by the FAA. The appendix presents actual data extracted from the FAA data base and used in this report. The data base contents are described below:

| COLUMN | DESCRIPTION OF COLUMN CONTENTS |
|---|---|
| EDATE | Date(mm/dd/yyyy) of ingestion event. |
| EVT# | FAA ingestion event sequence number reflecting order in which events were entered into the FAA bird ingestion data base. |
| ETIME | Local time of bird ingestion. |
| SIGN_EVT | Significant event factors.<br>AIRWRTHY - engine related airworthiness effects<br>INV POS LOSS - involuntary power loss<br>MULT BIRDS - multiple birds in 1 engine<br>MULT ENG - multiple engine ingestion (1 bird in each engine)<br>MULT ENG-BIRDS - multiple engine ingestion and 1 or both engines sustained multiple bird ingestion<br>TRVS FRAC - transverse fan blade fracture<br>OTHER - other significant factor, may be reported in narrative remarks<br>NONE - no significant factor noted |
| AIRCRAFT | Aircraft type. |
| ENGINE | Engine model.<br>(ALF502;JT15D;TFE731) - turbofan engines<br>(TPE331) - turboprop engine |
| DASH | Engine dash number |
| ENG_POS | Engine position of engine ingesting bird. Since each engine ingestion event has a unique record in the data base, duplicate event numbers indicate multiple engine ingestion events. This column provides record uniqueness in such cases. |
| DMG_CODE | Letter codes summarizing engine damage resulting from the bird ingestion. This column does not exist in the actual FAA data base, but was developed by the contractor to compress 17 YES/NO damage fields into a single column. A letter code appears for damage columns whose values are YES. Each page of damage information contains a legend identifying the damage type. In the explanation of damage |

codes below, a number in parentheses indicates the damage severity code which is further explained in the SEVERITY column. The data base column name is given in the explanation of the damage code.

- A(4) - ENG_DAM; engine damaged due to bird ingestion
- B(3) - LEAD_EDG; leading edge distortion/curl, minor fan blades
- C(3) - BEN/DEN; 1 to 3 fan blades bent or dented
- D(2) - BE/DE 3; more than 3 fan blades bent or dented
- E(3) - TORN 3; 1 to 3 fan blades torn
- F(2) - TORN 3; more than 3 fan blades torn
- G(2) - BROKEN; broken fan blade(s). leading edge and/or tip pieces missing; other blades also dented
- H(3) - SHINGLED; shingled (twisted) fan blades
- I(1) - TRVSFRAC; transverse fracture - a fan blade broken chordwise (across) and the piece liberated (includes secondary hard object damage)
- J(2) - SPINNER; dented, broken, or cracked spinner (includes spinner cap)
- K(1) - CORE; bent/broken compressor blades/vanes, blade/vane clash, blocked/disrupted airflow in low, intermediate, and high pressure compressors
- L(3) - NACELLE; dents and/or punctures to the engine enclosure (includes cowl)
- M(1) - FLANGE; flange separations
- N(2) - RELEASED; released (walked) fan blades (blade retention mechanism broken)
- O(1) - TURBINE; turbine damage
- P - OTHER; any damage not previously listed
- Q - UNKNOWN

NOTE: The maximum number of damage codes listed for an engine ingestion event is three. These three damage codes reflect the most severe damage that occurred. There may be other damage that occurred which is less severe that may be listed in the remarks column.

SEVERITY Numeric code indicating the severity of engine damage resulting from the bird ingestion. This column does not exist in the actual FAA data base, but was developed by the contractor as a result of an analysis of reported damage in the data base. The lower the severity code, the more severe the damage. The severity rating assigned to a flight is determined as the lowest severity rating attained by any of the damage categories. The corresponding severity ratings for each damage category were given in parentheses in the DMG_CODE discussion above.

Turbofan engine damage severity codes:

- 1 - most severe damage (damage is known)
- 2 - moderately severe damage (damage is known)
- 3 - least severe damage (damage is known)
- 4 - damage indicated, but not specified
- 9 - no damage reported

Turboprop engine damage severity codes:

- 1 - extremely severe damage (might jeopardize the airworthiness of the aircraft)

2 - severe damage (substantial damage which does not jeopardize the airworthiness of the aircraft)
3 - minor damage
4 - damage indicated, but not specified
9 - no damage reported

POW_LOSS — Degree of power loss as a result of bird ingestion
NONE - no power loss
EPR DEC - engine pressure ratio decrease
SPOOL DOWN - engine spooled down
N1 CHANGE - N1 rotor change
N2 CHANGE - N2 rotor change
COMPRESSOR - compressor surge/stall
UNKNOWN - unknown whether power loss occurred

MAX_VIBE — Maximum vibration reported as a dimensionless unit.

THROTTLE — Voluntary throttle change by crew in response to bird ingestion.
ADVANCE - voluntary throttle advance
RETARD - voluntary throttle retard
IDLE - voluntary throttle retard to idle
CUTOFF voluntary throttle retard to cutoff
NONE - no voluntary throttle change

IFSD — Indicate whether a voluntary in-flight shutdown occurred in response to bird ingestion.
NO - no shutdown
VIBES - shutdown due to vibrations
STAL/SURG - shutdown due to compressor stall/surge
HI EGT - shutdown due to high exhaust gas temperature
EPR - shutdown due to incorrect engine pressure ratio
INVLNTRY - involuntary engine shutdown
PARAMTRS - shutdown due to incorrect engine parameters
VLNTRY - voluntary engine shutdown
OTHER - other reasons, may be listed in remarks
UNKNOWN - unknown cause for shutdown

POF — Phase of flight during which bird ingestion occurred.
(TAXI;TAKEOFF;CLIMB;CRUISE;APPROACH;LANDING;UNKNOWN)

ALTITUDE — Altitude (ft. AGL) at time of bird ingestion.

SPEED — Air speed (knots) at time of bird ingestion.

FL_RULES — Flight rules in effect at time of bird ingestion.
IFR - instrument flight rules
VFR - visual flight rules
UNK - unknown

LT_COND — Light conditions at time of bird ingestion.
(DARK;LIGHT;DAWN;DUSK;etc.)

WEATHER — Weather conditions at time of bird ingestion.

CREW_AC Crew action taken in response to bird ingestion.
- ATO - aborted takeoff
- ATB - air turnback
- DIV - diversion
- UNK - unknown
- NONE - no crew action taken
- N/A - not applicable
- OTHER - some action taken, may be specified in narrative remarks

CREW_AL Indicates whether crew alerted to presence of birds at time of bird ingestion.
(YES;NO;UNKNOWN)

BIRD_SEE Indicates whether ingested bird(s) seen prior to ingestion
- NO - not seen
- YES - seen
- SEVERAL - 2 to 10 birds observed
- FLOCK - more than 10 birds observed

BIRD_NAM Common bird name. Trailing asterisk (*) implies bird not positively identified as such.

BIRD_SPE Species of positively identified bird. Alphanumeric identification code which conforms to Edward's† convention.

#_BIRDS Number of birds ingested. An asterisk (*) implies more than one bird but the exact count is unknown.

WT_OZ_1 Weight (oz.) of first ingested bird.

US_INCID Indicates whether bird ingestion occurred within US boundaries.
(YES;NO)

CTY_PRS Scheduled city pairs of aircraft operation.
(from code:to code) 3 letter city airport code.

AIRPORT Airport at which bird ingestion event occurred.
3 letter city airport code.

LOCALE Nearest town, state, country, etc.

REMARKS Narrative description providing additional information concerning some aspect of the ingestion.

† Edwards, E.P., "A Coded List of Birds of the World," IBSN:911882-04-9, 1974.

| EDATE | EVT# | ETIME | SIGN_EVT | AIRCRAFT | ENGINE | DASH | ENG_POS | DMG_CODE | SEVERITY | POW_L |
|---|---|---|---|---|---|---|---|---|---|---|
| 05/03/87 | 2 | 18:00:00 | MULT BIRDS | FALCON 50 | TFE731 | 3 | 1 LEFT | A,K | 1 | NONE |
| 05/11/87 | 3 | 18:45:00 | NONE | BAE125 | TFE731 | 5 | 1 LEFT | | 9 | NONE |
| 05/14/87 | 1 | 16:30:00 | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE |
| 05/14/87 | 25 | 15:30:00 | NONE | METRO | TPE331 | 11U | 1 LEFT | A,K | 3 | YES |
| 05/17/87 | 4 | 16:00:00 | MULT BIRDS | SABRE 65 | TFE731 | 3R | 1 LEFT | A,C,P | 3 | NONE |
| 05/20/87 | 7 | 9:30:00 | MULT BIRDS | CON 441 | TPE331 | 8 | 1 LEFT | | 9 | NONE |
| 05/22/87 | 8 | 5:30:00 | NONE | METRO II | TPE331 | 3UW | 1 LEFT | | 9 | NONE |
| 05/25/87 | 5 | | MULT BIRDS | FALCON 10 | TFE731 | 2 | 2 RIGHT | A,D | 2 | NONE |
| 05/25/87 | 52 | 15:30:00 | NONE | LEAR 35A | TFE731 | 2 | | A | 4 | |
| 05/26/87 | 6 | | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | A,D | 2 | NONE |
| 05/31/87 | 14 | | MULT ENG | LEAR 55 | TFE731 | 3A | 1 LEFT | A,K | 1 | NONE |
| 05/31/87 | 14 | | MULT ENG | LEAR 55 | TFE731 | 3A | 2 RIGHT | A,K | 1 | NONE |
| 06/17/87 | 9 | 14:00:00 | NONE | JETSTAR | TFE731 | 3 | 1 LEFT OUTBOARD | A,B,E | 3 | NONE |
| 06/17/87 | 10 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE |
| 06/21/87 | 20 | 21:30:00 | NONE | MU-2 | TPE331 | 5 | 2 RIGHT | | 9 | NONE |
| 07/01/87 | 33 | | NONE | FALCON 50 | TFE731 | 3 | 3 RIGHT | A,K | 1 | |
| 07/13/87 | 16 | 20:45:00 | NONE | BAE125-700 | TFE731 | 3R | 2 RIGHT | A,D | 2 | NONE |
| 07/14/87 | 17 | 16:00:00 | NONE | FALCON 50 | TFE731 | 3 | 2 CENTER | | 9 | NONE |
| 07/21/87 | 21 | 14:00:00 | NONE | METRO III | TPE331 | 11U | 1 LEFT | A,K | 3 | NONE |
| 07/22/87 | 22 | 11:30:00 | NONE | METRO III | TPE331 | 11U | 2 RIGHT | | 4 | YES |
| 07/27/87 | 18 | | NONE | LEAR 35 | TFE731 | 2 | 1 LEFT | A,C | 3 | NONE |
| 07/28/87 | 23 | 17:30:00 | NONE | METRO III | TPE331 | 11 | 1 LEFT | A,K | 3 | YES |
| 07/30/87 | 11 | 20:00:00 | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 07/31/87 | 12 | 8:40:00 | NONE | CL600 | ALF502 | L2 | 1 LEFT | A,D,H,L | 2 | NONE |
| 07/31/87 | 19 | 9:14:00 | MULT BIRDS | LEAR 35 | TFE731 | 2 | 1 LEFT | | 9 | NONE |
| 08/11/87 | 26 | 11:00:00 | MULT BIRDS | CASA 212 | TPE331 | 5 | 1 LEFT | A,K | 3 | NONE |
| 08/16/87 | 24 | 17:00:00 | NONE | LEAR 35A | TFE731 | 3A | 1 LEFT | A,C,P | 3 | |
| 08/24/87 | 38 | 11:00:00 | NONE | JS 31 | TPE331 | 10UG | 2 RIGHT | A,K | 3 | YES |
| 08/26/87 | 13 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | |
| 09/09/87 | 34 | 8:50:00 | NONE | LEAR 55 | TFE731 | 3AR | 2 RIGHT | A,E | 3 | NONE |
| 09/10/87 | 35 | 14:30:00 | MULT BIRDS | LEAR 35 | TFE731 | 2B | 1 LEFT | | 9 | NONE |
| 09/10/87 | 37 | 8:45:00 | MULT ENG-BIRDS | CITATION | TFE731 | 3 | 1 LEFT | A,D | 2 | NONE |
| 09/10/87 | 37 | 8:45:00 | MULT ENG-BIRDS | CITATION | TFE731 | 3 | 2 RIGHT | | 9 | NONE |
| 09/12/87 | 27 | 15:00:00 | MULT ENG | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,C,H | 3 | NONE |
| 09/12/87 | 27 | 15:00:00 | MULT ENG | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 09/14/87 | 28 | 8:5[illegible]:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 09/16/87 | 39 | 12:00:00 | NONE | JS 3101 | TPE331 | 10UF | 2 RIGHT | | 9 | NONE |
| 09/18/87 | 40 | 9:[illegible]:00 | NONE | JS 3101 | TPE331 | 10UF | 1 LEFT | | 9 | NONE |
| 09/20/87 | 36 | 12:00:00 | MULT BIRDS | BAE125-700 | TFE731 | 3R | 1 LEFT | A,D,H,K | 1 | NONE |
| 09/22/87 | 41 | | NONE | METRO | TPE331 | 10 | 1 LEFT | A,K | 3 | YES |
| 09/22/87 | 44 | | NONE | METRO 4 | TPE331 | 11U | 2 RIGHT | A,K,P | 3 | |
| 09/28/87 | 42 | 13:00:00 | NONE | JS 3101 | TPE331 | 10UG | 2 RIGHT | A,P | 3 | YES |
| 10/01/87 | 45 | 9:4[illegible]:00 | NONE | JS 31 | TPE331 | 10UG | 2 RIGHT | | 9 | |
| 10/05/87 | 29 | 13:30:00 | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,B,C | 3 | NONE |
| 10/08/87 | 30 | 19:45:00 | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 10/13/87 | 43 | 9:00:00 | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | A,D,K,P | 1 | NONE |
| 10/13/87 | 46 | 22:00:00 | NONE | BAE 3101 | TPE331 | 10UG | 2 RIGHT | | 9 | NONE |
| 10/27/87 | 47 | 20:00:00 | NONE | JS 3101 | TPE331 | 10 | 2 RIGHT | A,K | 3 | FLAM |
| 10/30/87 | 55 | 12:[illegible]0:00 | NONE | METRO 3 | TPE331 | 11U | 1 LEFT | | 9 | NONE |
| 11/02/87 | 50 | 8:[illegible]5:00 | NONE | CITATION3 | TFE731 | 3B | 2 RIGHT | | 9 | NONE |
| 11/04/87 | 31 | 14:[illegible]5:00 | MULT ENG-BIRDS | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE |
| 11/04/87 | 31 | 14:55:00 | MULT ENG-BIRDS | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE |
| 11/06/87 | 51 | 7:30:00 | NONE | METRO | TPE331 | 11U | 1 LEFT | A,K | 3 | NO |
| 11/11/87 | 56 | 12:[illegible]0:00 | NONE | JS 31 | TPE331 | 10UF | 1 LEFT | A,K,P | 3 | NONE |
| 11/19/87 | 53 | 9:[illegible]:00 | NONE | BAE125-800 | TFE731 | 5R | 2 RIGHT | A,D,P | 2 | NONE |
| 11/23/87 | 57 | 19:30:00 | NONE | METRO III | TPE331 | 11U | 2 RIGHT | | 9 | NONE |
| 11/29/87 | 32 | 17:00:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 12/03/87 | 54 | | NONE | FALCON 10 | TFE731 | 2 | 2 RIGHT | | 9 | NONE |
| 12/05/87 | 64 | 19:00:00 | NONE | TCOMM 695B | TPE331 | 10R | 2 RIGHT | A,K | 3 | NONE |
| 12/10/87 | 48 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,C,H | 3 | NONE |
| 12/11/87 | 49 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 12/11/87 | 70 | 18:30:00 | MULT BIRDS | JS 31 | TPE331 | 10UF | 2 RIGHT | A,K | 3 | YES |

| DMG_CODE | SEVERITY | POW_LOSS | MAX_VIBE | THROTTLE | IFSD | POF | ALTITUDE | SPEED | FL_RULES | LT_CONDS | WEATHER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A,K | 1 | NONE | | NONE | NO | LANDING | 0 | 122 | VFR | DUSK | SCATTERED |
| | 9 | NONE | | NONE | NO | LANDING | 25 | 125 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | TAKEOFF | | | | LIGHT | CLEAR |
| A,K | 3 | YES | YES | | NO | LANDING | 10 | 90 | VFR | LIGHT | CLEAR |
| A,C,P | 3 | NONE | NONE | NONE | NO | TAKEOFF | | | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 25 | 125 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 150 | | VFR | LIGHT | CLEAR |
| A,D | 2 | NONE | | NONE | NO | LANDING | 100 | 100 | VFR | LIGHT | CLEAR |
| A | 4 | | NONE | | NO | APPROACH | 200 | 160 | VFR | LIGHT | CLEAR |
| A,D | 2 | NONE | NONE | | NO | TAKEOFF | | | VFR | LIGHT | CLEAR |
| A,K | 1 | NONE | NONE | NONE | NO | TAKEOFF | 150 | | IFR | LIGHT | CLEAR |
| A,K | 1 | NONE | NONE | NONE | NO | TAKEOFF | 150 | | IFR | LIGHT | CLEAR |
| A,B,E | 3 | NONE | NONE | NONE | NO | TAKEOFF | 200 | 100 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | UNKNOWN | | | | | |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 1500 | 150 | VFR | DARK | CLEAR |
| A,K | 1 | | NONE | | NO | UNKNOWN | | | | | |
| A,D | 2 | NONE | YES | NONE | NO | LANDING | 300 | 117 | VFR | DUSK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 6000 | 140 | VFR | LIGHT | SCATTERED |
| A,X | 3 | NONE | NONE | RETARD | NO | TAKEOFF | 0 | | VFR | LIGHT | SCATTERED |
| | 4 | YES | NONE | | NO | TAKEOFF | 0 | 100 | VFR | LIGHT | CLEAR |
| A,C | 3 | NONE | NONE | NONE | NO | UNKNOWN | | | IFR | LIGHT | CLEAR |
| A,K | 3 | YES | NONE | | NO | TAKEOFF | 0 | 100 | VFR | DAWN | CLEAR |
| | 9 | NONE | | NONE | NO | TAXI | 0 | 0 | VFR | DUSK | CLEAR |
| A,D,H,L | 2 | NONE | YES | NONE | NO | TAKEOFF | 35 | 140 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 120 | VFR | LIGHT | CLEAR |
| A,K | 3 | NONE | NONE | NONE | NO | CLIMB | 800 | 110 | VFR | LIGHT | RAIN |
| A,C,P | 3 | | HIGH | | | TAKEOFF | | -V1 | VFR | LIGHT | CLEAR |
| A,K | 3 | YES | | | YES | CRUISE | 450 | 180 | VFR | LIGHT | CLEAR |
| | 9 | | | NONE | NO | UNKNOWN | | | | | |
| A,E | 3 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 110 | VFR | LIGHT | OVERCAST |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 128 | VFR | LIGHT | CLEAR |
| A,D | 2 | NONE | NONE | NONE | NO | LANDING | 240 | 150 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | LANDING | 240 | 150 | VFR | LIGHT | CLEAR |
| A,C,H | 3 | NONE | | NONE | NO | TAKEOFF | 100 | 120 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | TAKEOFF | 100 | 120 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | SHUT OFF | NO | LANDING | 0 | 85 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | LANDING | | | VFR | LIGHT | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 100 | 125 | VFR | LIGHT | OVERCAST |
| A,D,H,K | 1 | NONE | MINOR | NONE | NO | TAKEOFF | 30 | 125 | VFR | LIGHT | OVERCAST |
| H,K | 3 | YES | | ADVANCE | NO | CLIMB | | | | DARK | |
| H,K,P | 3 | | NONE | NONE | NO | CLIMB | | | VFR | DARK | CLEAR |
| A,P | 3 | YES | NONE | NONE | NO | TAKEOFF | 320 | 120 | IFR | LIGHT | CLEAR |
| | 9 | | | NONE | NO | APPROACH | 200 | 120 | VFR | LIGHT | CLEAR |
| A,B,C | 3 | NONE | | NONE | NO | UNKNOWN | | | | LIGHT | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | LANDING | 200 | | | DARK | SCATTERED |
| A,D,K,P | 1 | NONE | NONE | NONE | NO | TAKEOFF | 20 | 130 | VFR | LIGHT | OVERCAST |
| | 9 | NONE | NONE | NONE | NO | APPROACH | | 120 | IFR | DARK | CLEAR |
| A,K | 3 | FLAME OUT | NONE | CUTOFF | INVOLUNT | APPROACH | 2000 | 150 | VFR | DARK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | LANDING | 0 | 80 | VFR | LIGHT | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | CRUISE | 2500 | 250 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | LANDING | | | VFR | LIGHT | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | LANDING | | | VFR | LIGHT | SCATTERED |
| H,K | 3 | NO | HIGH | CUTOFF | VIBES | TAKEOFF | 900 | 110 | VFR | LIGHT | CLEAR |
| A,K,P | 3 | NONE | NONE | NONE | NO | LANDING | 0 | 90 | | LIGHT | OVERCAST |
| A,D,P | 2 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 120 | VMC | LIGHT | OVERCAST |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 30 | | IFR | DUSK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | UNKNOWN | | | | DUSK | |
| | 9 | NONE | | NONE | NO | APPROACH | 4000 | 190 | VFR | DARK | CLEAR |
| A,K | 3 | NONE | NONE | NONE | NO | APPROACH | 150 | 130 | VFR | DUSK | CLEAR |
| A,C,H | 3 | NONE | NONE | | NO | UNKNOWN | | | | | |
| | 9 | NONE | NONE | | NO | UNKNOWN | | | | | |
| A,K | 3 | YES | SOME | NONE | NO | TAKEOFF | 0 | 80 | IFR | DARK | OVERCAST |

| EDATE | EVT# | CREW_AC | CREW_AL | BIRD_SEE | BIRD_NAM | BIRD_SPE | #_BIRDS | WT_OZ_1 | US_INCID | CTY_PRS | AIRPORT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/03/87 | | NONE | | SEVERAL | SEAGULL* | | 3 | 24.0 | YES | | DTW |
| 05/11/87 | | NONE | YES | YES | RING-BILLED GULL | 14N12 | 1 | 17.0 | YES | | BKL |
| 05/14/87 | | NONE | NO | ONE | SPARROW* | | 1 | | NO | | LEEDS |
| 05/14/87 | | NONE | NO | NO | | | 1 | | YES | | PSC |
| 05/17/87 | | NONE | | FLOCK | MORNING DOVE | 2P105 | * | 4.0 | YES | | MSY |
| 05/20/87 | | NONE | NO | NO | STARLING* | | * | 8.0 | YES | | EVV |
| 05/22/87 | | ATB | NO | ONE | COMMON GULL | 14N13 | 1 | 15.0 | NO | | LDK |
| 05/25/87 | | NONE | NO | SEVERAL | HAWK* | | 2 | | NO | | LIN |
| 05/25/87 | | | NO | ONE | SEAGULL* | | 1 | 64.0 | NO | | FLCH |
| 05/26/87 | | NONE | NO | | PIGEON* | | 1 | 16.0 | NO | | SCL |
| 05/31/87 | | NONE | NO | SEVERAL | GULL* | | 1 | 16.0 | NO | | |
| 05/31/87 | | NONE | NO | SEVERAL | GULL* | | 1 | 16.0 | NO | | |
| 06/17/87 | | NONE | YES | YES | HERRING GULL | 14N14 | 1 | 40.0 | YES | | SIE |
| 06/17/87 | | NONE | NO | NO | | | 1 | | NO | | |
| 06/21/87 | | NONE | NO | NO | DOVE* | | 1 | | YES | | ROD |
| 07/01/87 | | NONE | NO | NO | | | | | NO | | |
| 07/13/87 | | NONE | YES | YES | YELLOW CROWN NIGHT HERON | 1I27 | 1 | 24.0 | YES | | MSY |
| 07/14/87 | | NONE | NO | ONE | CHIMNEY SWIFT | | 1 | 1.0 | YES | | STL |
| 07/21/87 | | ATO | NO | ONE | SEAGULL* | | 1 | 16.0 | YES | | TVC |
| 07/22/87 | | NONE | NO | YES | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | | CWA |
| 07/27/87 | | NONE | NO | NO | KILLDEER | 5N33 | 1 | 3.0 | YES | | PHX |
| 07/28/87 | | ATO | NO | NO | ROCK DOVE | 2P1 | 1 | 14.0 | YES | | LAX |
| 07/30/87 | | NONE | NO | NO | TREE SPARROW | 70Z23 | 1 | 1.0 | NO | | LANZHO |
| 07/31/87 | | ATB | YES | ONE | BARHMING KITE | 3K31 | 1 | 20.0 | NO | | BAYAN |
| 07/31/87 | | NONE | NO | FLOCK | ROCK DOVE | 2P1 | * | 14.0 | YES | | TOA |
| 08/11/87 | | ATB | NO | SEVERAL | SEAGULL* | | 2 | 32.0 | NO | | |
| 08/16/87 | | ATO | | | RING-BILLED GULL | 14N12 | 1 | 16.0 | NO | | |
| 08/24/87 | | DIV | YES | ONE | COMMON WHITE SEAGULL* | | 1 | 32.0 | NO | | |
| 08/26/87 | | NONE | NO | NO | | | 1 | | YES | | |
| 09/09/87 | | NONE | NO | ONE | GREATER YELLOWLEGS | 6N19 | 1 | 6.6 | YES | | FLD |
| 09/10/87 | | NONE | NO | YES | SPARROW* | | * | 7.7 | YES | | |
| 09/10/87 | | NONE | NO | YES | STARLING* | | 2 | 4.0 | YES | | GRR |
| 09/10/87 | | NONE | NO | YES | STARLING* | | 1 | 4.0 | YES | | GRR |
| 09/12/87 | | ATB | NO | FLOCK | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | CMH-IAD | CMH |
| 09/12/87 | | ATB | NO | FLOCK | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | CMH-IAD | CMH |
| 09/14/87 | | NONE | NO | ONE | | | 1 | | NO | POL-HOR | HORTA |
| 09/16/87 | | NONE | NO | ONE | | | 1 | | YES | | ATL |
| 09/13/87 | | NONE | NO | ONE | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | | |
| 09/20/87 | | ATB | YES | YES | CANADA GOOSE | 2J30 | 2 | 128.0 | YES | | |
| 09/22/87 | | ATB | NO | | | | 1 | | YES | | |
| 09/22/87 | | NONE | NO | NO | SEAGULL* | | | | YES | | |
| 09/28/87 | | NONE | NO | NO | | | 1 | 16.0 | YES | | |
| 10/01/87 | | NONE | NO | ONE | | | 1 | | YES | | MEM |
| 10/05/87 | | NONE | | NO | | | 1 | | YES | YKM-PSC | |
| 10/08/87 | | NONE | YES | ONE | COMMON LAPWING | 5N1 | 1 | 7.7 | NO | PWK-PWK | PWK |
| 10/13/87 | | ATB | NO | NO | SEAGULL* | | 1 | 16.0 | NO | | CVT |
| 10/13/87 | | NONE | NO | NO | | | 1 | | YES | | |
| 10/27/87 | | IFSD | NO | NO | OWL* | | 1 | | YES | | |
| 10/30/87 | | NONE | NO | FLOCK | SEAGULL* | | 1 | | NO | | |
| 11/02/87 | | NONE | NO | NO | | | 1 | | YES | | FRG |
| 11/04/87 | | NONE | YES | SEVERAL | REDWINGED BLACKBIRD | 64Z54 | * | 2.0 | YES | LAX-CCR | CCR |
| 11/04/87 | | NONE | YES | SEVERAL | REDWINGED BLACKBIRD | 64Z54 | * | 2.0 | YES | LAX-CCR | CCR |
| 11/06/87 | | ATB | NO | ONE | SEAGULL* | | 1 | 32.0 | YES | | SBA |
| 11/11/87 | | NONE | NO | ONE | MALLARD | 2J84 | 1 | 36.0 | NO | | |
| 11/19/87 | | NONE | YES | ONE | BLACK-HEADED GULL | 14N36 | 1 | 10.0 | NO | | EDVE |
| 11/23/87 | | NONE | NO | FLOCK | SEAGULL * | | 1 | 8.0 | NO | | BSL |
| 11/29/87 | | NONE | | | | | 1 | | YES | SNA-SJC | |
| 12/03/87 | | NONE | NO | SEVERAL | FRANKLIN'S GULL | 14N31 | 1 | 9.0 | YES | | MKC |
| 12/05/87 | | NONE | NO | NO | | | 1 | | NO | | HLP |
| 12/10/87 | | NONE | NO | NO | | | 1 | | NO | | |
| 12/11/87 | | NONE | NO | NO | | | 1 | | NO | | HARARE |
| 12/11/87 | | ATO | NO | NO | COMMON LAPWING | 5N1 | * | 7.7 | NO | | |

| US_INCID | CTY_PRS | AIRPORT | LOCALE | REMARKS |
|---|---|---|---|---|
| YES | | DTW | DETROIT, MICHIGAN | COMP STATORS BENT |
| YES | | BKL | CLEVELAND, OH | |
| NO | | LEEDS | LEEDS, ENGLAND | |
| YES | | PSC | PASCO, WA | 1+2STG IMP DAM, 1BENT BLADE |
| YES | | MSY | NEW ORLEANS, LA | COMP STATORS DAMAGED |
| YES | | EVV | EVANSVILLE, INDIANA | |
| NO | | LDK | LINKOPING, SWEDEN | |
| NO | | LIN | MILANO, ITALY | 5 F BLDS WERE BENT |
| NO | | FLCH | LONDON, UK | |
| NO | | SCL | SANTIAGO, CHILE | |
| NO | | | THESSALONIKI, GREECE | 1 1STG LPC BLD BENT TO FWD SIDE |
| NO | | | THESSALONIKI, GREECE | 1 1STG LPC BLD BENT TO FWD SIDE |
| YES | | SIE | SEA ISLE CITY, NJ | 3 F BLDS TIP CURL |
| NO | | | OXFORD, ENGLAND | |
| YES | | RDD | REDDING, CA | |
| NO | | | | ODOR,FAN STATOR DAMAGED |
| YES | | MSY | NEW ORLEANS, LA | |
| YES | | STL | ST. LOUIS, MO | |
| YES | | TVC | TRAVERSE CITY AIRPORT MI | BENT IMP BLD |
| YES | | CWA | WAUSAU, WI | |
| YES | | PHX | PHOENIX, ARIZONA | |
| YES | | LAX | LOS ANGELES, CA | IMP DAMAGE |
| NO | | LANZHO | CHINA | |
| NO | | BAYAN | PENANG, MALAYSIA | 12 EXIT GUIDE VANES DAMAGED |
| YES | | TOA | TORRANCE, CA | |
| NO | | | VALPARAISO,CHILE NAVALBASE | 1ST IMP DAMAGE |
| NO | | | LINDSAY, ONTARIO, CANADA | FAN STATOR DAMAGE |
| NO | | | DUMFRIES, SCOTLAND | 75% IMP VANES BENT/CURLED OVER, ODOR |
| YES | | | | |
| YES | | FLD | BEDFORD, MA | ODOR |
| YES | | | SHIDELY, SARATOGA, WY | |
| YES | | GRR | GRAND RAPIDS, MI | |
| YES | | GRR | GRAND RAPIDS, MI | |
| YES | CMH-IAD | CMH | COLOMBUS, OHIO | 2 F BLDS DAMAGED |
| YES | CMH-IAD | CMH | COLOMBUS, OHIO | |
| NO | POL-HOR | HORTA | AZORES, PORTUGAL | |
| YES | | ATL | ATLANTA, GA | |
| YES | | | VANDALIA, OHIO | |
| YES | | | WATERBURY, OXFORD, CONN | 4 LP COMP STATOR VANED DEATTACHED |
| YES | | | MANION AIRPORT, ILL | PM EVT, 6 IMP BLDS BENT, 2 SEVERELY |
| YES | | | VICTORIA, LA | PM EVT, 16% TQ LOSS ON POST GRD RUN |
| YES | | | MIDDLETOWN, MD | FUEL NOZZLES AND COMBUSTOR CAN CLOGGED |
| YES | | MEM | MEMPHIS, TENN | FUEL NOZZLES REMOVED FOR CLEANING |
| YES | YKM-PSC | | PASCO, WASHINGTON | FOUND ON GRD INSPEC |
| NO | PWK-PWK | PWK | AYRESHIRE, SCOTLAND | |
| NO | | CVT | CHESTER, UK | 5 FAN BLADES+1ST STG COMP DAM |
| YES | | | ERIE, PA | |
| YES | | | MEMPHIS, TENN | IMP BLADES BENT |
| NO | | | SCHIPOL INT., AMSTERDAM | PROPELLOR DAMAGE |
| YES | | FRG | QUEEN, NY | SLIGHT NICK ON A FAN BLADE |
| YES | LAX-CCR | CCR | CONTRA COSTA, CONCORD CA | |
| YES | LAX-CCR | CCR | CONTRA COSTA, CONCORD CA | |
| YES | | SBA | SANTA BARBARA, CA | SEVERAL 1 STG IMP VANES BENT |
| NO | | | DUNSFOLD, ENGLAND | 1STG IMP BENT OVER AT TIP (1''),T2 PROBE |
| NO | | EDVE | BRAUNSHWEIG, FRG | 4 FAN BLADES AND STATOR DAMAGED |
| NO | | BSL | BASLE, SWITZERLAND | |
| YES | SNA-SJC | | SAN JOSE, CA | FOUND ON POSTFLIGHT INSPECTION |
| YES | | MKC | KANAS CITY, MO | |
| NO | | HLP | JAKARTA, INDONESIA | 2 1 STG IMPELLER BLDS BENT |
| NO | | | | FOUND ON GRD INSPEC |
| NO | | HARARE | AFRICA | |
| NO | | | WOODFORD, ENGLAND | MOMENTARY 20% TQ LOSS, IMP DAMAGE |

| EDATE | EVT# | ETIME | SIGN_EVT | AIRCRAFT | ENGINE | DASH | ENG_POS | DMG_CODE | SEVERITY | POW_L |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/13/87 | 65 | 16:00:00 | MULT ENG-BIRDS | JETSTAR | TFE731 | 3 | 2 LEFT INBOARD | A,D,K | 1 | NONE |
| 12/13/87 | 65 | 16:00:00 | MULT ENG-BIRDS | JETSTAR | TFE731 | 3 | 4 RIGHT OUTBOARD | A,D | 2 | NONE |
| 12/13/87 | 65 | 16:00:00 | MULT ENG-BIRDS | JETSTAR | TFE731 | 3 | 3 RIGHT INBOARD | A,D | 2 | NONE |
| 12/16/87 | 98 | 18:00:00 | NONE | BAE125 | TFE731 | 3R | 2 RIGHT | A,D | 2 | NONE |
| 12/17/87 | 71 | 8:05:00 | MULT ENG-BIRDS | DO 228 | TPE331 | 5 | 1 LEFT | A,K | 3 | |
| 12/17/87 | 71 | 8:05:00 | MULT ENG-BIRDS | DO 228 | TPE331 | 5 | 2 RIGHT | A,K | 3 | |
| 12/30/87 | 99 | 16:00:00 | NONE | LEAR 35A | TFE731 | 2 | 2 RIGHT | A,D,K | 1 | YES |
| 01/07/88 | 162 | | MULT ENG-BIRDS | LEAR 35 | TFE731 | 2 | 2 RIGHT | A,D,G | 2 | YES |
| 01/07/88 | 162 | | MULT ENG-BIRDS | LEAR 35 | TFE731 | 2 | 1 LEFT | A,D,G | 2 | YES |
| 01/13/88 | 58 | 10:57:00 | INV POW LOSS | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | A,C,E,K | 1 | COMPR |
| 01/15/88 | 63 | 14:00:00 | NONE | CITATION 3 | TFE731 | 3B | 2 RIGHT | A,C,H | 3 | NONE |
| 01/16/88 | 59 | 11:40:00 | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,C | 3 | NONE |
| 01/22/88 | 77 | 7:00:00 | NONE | COMM 681 | TPE331 | 43BL | 2 RIGHT | | 9 | NONE |
| 02/03/88 | 60 | 18:40:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 02/11/88 | 68 | 22:22:00 | NONE | BAE125-700 | TFE731 | 3R | 2 RIGHT | | 9 | NONE |
| 02/15/88 | 61 | 12:30:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 02/16/88 | 78 | 8:50:00 | NONE | DO 228 | TPE331 | 5 | 2 RIGHT | A,K | 3 | YES |
| 02/18/88 | 62 | 6:50:00 | MULT ENG-BIRDS | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE |
| 02/18/88 | 62 | 6:50:00 | MULT ENG-BIRDS | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 02/22/88 | 69 | 21:00:00 | MULT BIRDS | LEAR 35A | TFE731 | 2 | 2 RIGHT | A,B,D,K | 1 | YES |
| 02/22/88 | 75 | 11:00:00 | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | | 9 | NONE |
| 03/04/88 | 85 | 19:30:00 | INV POW LOSS | MU 2 | TPE331 | 10 | 1 LEFT | A,K | 3 | SPOOL |
| 03/05/88 | 79 | 16:45:00 | OTHER | METRO | TPE331 | 11 | 1 LEFT | A,K,P | 2 | |
| 03/09/88 | 80 | 7:00:00 | NONE | DO 228 | TPE331 | 5 | 2 RIGHT | A,K | 3 | NONE |
| 03/10/88 | 72 | 9:45:00 | NONE | BAE146 | ALF502 | R3A | 2 LEFT INBOARD | | 9 | NONE |
| 03/14/88 | 86 | 15:00:00 | NONE | DO 228 | TPE331 | 5 | 2 RIGHT | | 4 | YES |
| 03/22/88 | 76 | 20:40:00 | NONE | BAE125-700 | TFE731 | 3R | 2 RIGHT | | 9 | NONE |
| 03/22/88 | 83 | 10:15:00 | NONE | LEAR C21A | TFE731 | 2 | 2 RIGHT | | 9 | NONE |
| 03/23/88 | 87 | 19:55:00 | NONE | METRO | TPE331 | 11U | 1 LEFT | A,K | 4 | NONE |
| 03/25/88 | 73 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 03/29/88 | 74 | 21:00:00 | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 04/04/88 | 92 | 6:45:00 | MULT BIRDS | FALCON 10 | TFE731 | 2 | 2 RIGHT | A,G,I,K | 1 | FLAME |
| 04/09/88 | 84 | 10:15:00 | NONE | WESTWIND | TFE731 | 3 | 2 RIGHT | A,D,G,K | 1 | MOMENT |
| 04/12/88 | 100 | 8:30:00 | NONE | WESTW 1124 | TFE731 | 3 | 2 RIGHT | A,D | 2 | YES |
| 04/18/88 | 102 | 17:00:00 | NONE | CASA 212 | TPE331 | 5 | 2 RIGHT | A,K | 3 | YES |
| 04/24/88 | 88 | 14:15:00 | NONE | T47A | JT15D | 5 | 1 LEFT | | 9 | NONE |
| 04/25/88 | 81 | | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 04/27/88 | 82 | 22:00:00 | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | A,L | 3 | NONE |
| 05/01/88 | 89 | | NONE | BAE146 | ALF502 | R3A | 2 LEFT INBOARD | | 9 | NONE |
| 05/02/88 | 94 | 8:50:00 | NONE | CESSNA 550 | JT15D | 4 | | | 9 | |
| 05/03/88 | 114 | 13:42:00 | NONE | METRO | TPE331 | 11U | 1 LEFT | A,K | 3 | NONE |
| 05/04/88 | 110 | 15:30:00 | NONE | BAE125 | TFE731 | 3R | 2 RIGHT | A,L | 3 | NONE |
| 05/05/88 | 93 | 10:35:00 | NONE | CESSNA 552 | JT15D | 5 | 1 LEFT | | 9 | NONE |
| 05/10/88 | 90 | 16:00:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 05/20/88 | 101 | 13:00:00 | OTHER | LEAR 35 | TFE731 | 2 | 1 LEFT | A,C,P | 3 | |
| 05/27/88 | 103 | 20:40:00 | NONE | COMM 980 | TPE331 | 25 | 2 RIGHT | | 9 | |
| 05/30/88 | 91 | 21:00:00 | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE |
| 06/04/88 | 97 | 19:30:00 | NONE | WESTWIND | TFE731 | 3 | 1 LEFT | | 9 | NONE |
| 06/08/88 | 119 | 8:30:00 | NONE | METRO III | TPE331 | 11U | 1 LEFT | | 9 | NONE |
| 06/11/88 | 111 | | NONE | LEAR 36 | TFE731 | 2 | 1 LEFT | A,C | 3 | |
| 06/20/88 | 95 | 9:40:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 06/20/88 | 115 | 9:00:00 | NONE | METRO | TPE331 | 11U | 2 RIGHT | | 9 | NONE |
| 06/20/88 | 116 | 19:50:00 | NONE | CITAT 500 | JT15D | 1A | 2 RIGHT | A,G | 2 | N1 CHA |
| 06/27/88 | 112 | 3:00:00 | NONE | LEAR 35 | TFE731 | 2 | 1 LEFT | A,B,C,P | 3 | NONE |
| 06/30/88 | 96 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 07/01/88 | 113 | 14:30:00 | NONE | LEAR 35 | TFE731 | 2 | 1 LEFT | | 9 | NONE |
| 07/05/88 | 120 | 8:00:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | | 9 | NONE |
| 07/05/88 | 121 | 14:00:00 | NONE | JS 3101 | TPE331 | 10UF | 1 LEFT | | 9 | NONE |
| 07/06/88 | 122 | 12:05:00 | NONE | COMM 1000 | TPE331 | 10 | 1 LEFT | | 9 | SPOOL |
| 07/11/88 | 104 | | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |
| 07/12/88 | 105 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 07/15/88 | 106 | | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE |

| _CODE | SEVERITY | POW_LOSS | MAX_VIBE | THROTTLE | IFSD | POF | ALTITUDE | SPEED | FL_RULES | LT_CONDS | WEATHER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D.K | 1 | NONE | NONE | NONE | NO | TAKEOFF | 50 | 160 | VFR | DUSK | OVERCAST |
| D | 2 | NONE | NONE | NONE | NO | TAKEOFF | 50 | 160 | VFR | DUSK | OVERCAST |
| D | 2 | NONE | NONE | NONE | NO | TAKEOFF | 50 | 160 | VFR | DUSK | OVERCAST |
| D | 2 | NONE | NONE | NONE | NO | APPROACH | 1200 | 160 | VFR | DUSK | CLEAR |
| K | 3 | | NONE | RETARD | NO | LANDING | 0 | 80 | VFR | LIGHT | CLEAR |
| K | 3 | | NONE | RETARD | NO | LANDING | 0 | 80 | VFR | LIGHT | CLEAR |
| .K | 1 | YES | NONE | NONE | NO | CLIMB | | | VFR | LIGHT | CLEAR |
| D.G | 2 | YES | SOME | | NO | TAKEOFF | 0 | 130 | IFR | | OVERCAST |
| D.G | 2 | YES | SOME | | NO | TAKEOFF | 0 | 130 | IFR | | OVERCAST |
| C.E,K | 1 | COMPRESSOR | | IDLE | INVOLUNTA | TAKEOFF | 800 | | VFR | LIGHT | CLEAR |
| .H | 3 | NONE | SOME | NONE | NO | TAKEOFF | | 110 | VFR | LIGHT | CLEAR |
| C | 3 | NONE | | | NO | UNKNOWN | | | | DARK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 40 | 100 | VFR | DAWN | SCATTERED |
| | 9 | NONE | 1.2 | IDLE | NO | LANDING | | 115 | VFR | DUSK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 120 | IFR | DARK | FOG |
| | 9 | NONE | .6 | | NO | TAKEOFF | | 120 | IFR | LIGHT | CLEAR |
| K | 3 | YES | NONE | CUTOFF | VOLUNTARY | TAKEOFF | 0 | 100 | VFR | LIGHT | CLEAR |
| | 9 | NONE | .3 | | NO | LANDING | | 115 | VFR | LIGHT | CLEAR |
| | 9 | NONE | .3 | | NO | LANDING | | 115 | VFR | LIGHT | CLEAR |
| B.D,K | 1 | YES | HIGH | NONE | NO | LANDING | 20 | 120 | VFR | DARK | CLEAR |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 400 | 140 | VFR | LIGHT | CLEAR |
| K | 3 | SPOOL DOWN | HIGH | CUT OFF | INVOLUNTA | APPROACH | 100 | | | DARK | DRY |
| K,P | 2 | | | CUTOFF | VOLUNTARY | APPROACH | 1000 | 160 | | DUSK | OVERCAST |
| K | 3 | NONE | | IDLE | NO | TAKEOFF | 0 | 70 | VFR | LIGHT | CLEAR |
| | 9 | NONE | .2 | NONE | NO | LANDING | 0 | 80 | VFR | LIGHT | CLEAR |
| | 4 | YES | YES | | NO | LANDING | 0 | 70 | VFR | LIGHT | SCATTERED |
| | 9 | NONE | | NONE | NO | APPROACH | 2000 | 130 | IFR | DARK | SNOW |
| | 9 | NONE | NONE | RETARD | NO | TAKEOFF | 0 | 95 | | LIGHT | SCATTERED |
| K | 4 | NONE | NONE | NONE | NO | UNKNOWN | 600 | 130 | | LIGHT | SCATTERED |
| | 9 | NONE | | | NO | UNKNOWN | | | | | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | VFR | DARK | |
| G.I,K | 1 | FLAME OUT | HIGH | | YES | TAKEOFF | 0 | 100 | VFR | LIGHT | SCATTERED |
| D.G,K | 1 | MOMENTARY | SMALL | NONE | NO | TAKEOFF | 300 | 160 | | LIGHT | CLEAR |
| D | 2 | YES | NONE | | NO | CLIMB | 3000 | 170 | VFR | LIGHT | CLEAR |
| K | 3 | YES | HIGH | | NO | LANDING | 0 | 80 | VFR | LIGHT | CLEAR |
| I | 9 | NONE | NONE | NONE | NO | APPROACH | 2300 | 180 | IFR | LIGHT | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| L | 3 | NONE | | | NO | UNKNOWN | | | | DARK | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | | | | NO | APPROACH | | 170 | IFR | LIGHT | RAIN/SNOW |
| K | 3 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 120 | VFR | LIGHT | CLEAR |
| L | 3 | NONE | NONE | NONE | NO | LANDING | 10 | 122 | VFR | LIGHT | OVERCAST |
| I | 9 | NONE | | NONE | NO | UNKNOWN | | | VFR | LIGHT | CLEAR |
| I | 9 | NONE | | | NO | UNKNOWN | | | VFR | | |
| .P | 3 | | SOME | CUTOFF | VIBES | TAKEOFF | 0 | | VFR | LIGHT | CLEAR |
| | 9 | | NONE | | NO | UNKNOWN | 2000 | 130 | IFR | DARK | SNOW |
| | 9 | NONE | | | NO | UNKNOWN | | | | DARK | |
| I | 9 | NONE | NONE | NONE | NO | TAKEOFF | 0 | 120 | | LIGHT | CLEAR |
| | 9 | NONE | NONE | | NO | APPROACH | 900 | 180 | IFR | LIGHT | SCATTERED |
| I | 3 | | | NONE | NO | UNKNOWN | | | | | |
| I | 9 | NONE | 0.2 | | NO | LANDING | | | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 50 | 100 | VFR | LIGHT | SCATTERED |
| I | 2 | N1 CHANGE | NONE | IDLE | NO | CLIMB | 1300 | 148 | IFR | DAY | CLEAR |
| B.C,P | 3 | NONE | NONE | NONE | NO | APPROACH | 100 | 125 | VFR | DARK | CLEAR |
| I | 9 | NONE | | | NO | UNKNOWN | | | | | |
| I | 9 | NONE | NONE | NONE | NO | LANDING | 10 | | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 1300 | 120 | VFR | LIGHT | OVERCAST |
| I | 9 | NONE | NONE | NONE | NO | APPROACH | 1500 | 120 | VFR | LIGHT | HAZZY |
| I | 9 | SPOOL DOWN | | CUTOFF | YES | TAKEOFF | 50 | 110 | VFR | LIGHT | CLEAR |
| I | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |

| EDATE | EVT#.CREW_AC | CREW_AL | BIRD_SEE | BIRD_NAM | BIRD_SPE | #_BIRDS | WT_OZ_1 | US_INCID | CTY_PRS | AIRP |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/13/87 | ATB | NO | FLOCK | COMMON LAPWING | 5N1 | * | 7.7 | NO | | |
| 12/13/87 | ATB | NO | FLOCK | COMMON LAPWING | 5N1 | * | 7.7 | NO | | |
| 12/13/87 | ATB | NO | FLOCK | COMMON LAPWING | 5N1 | * | 7.7 | NO | | |
| 12/16/87 | NONE | NO | NO | | | 1 | | YES | | |
| 12/17/87 | NONE | NO | FLOCK | GULL* | | * | 8.0 | NO | | FDH |
| 12/17/87 | NONE | NO | FLOCK | SEAGULL* | | * | 8.0 | NO | | FDH |
| 12/30/87 | NONE | NO | NO | | | 1 | | NO | | |
| 01/07/88 | DIV | NO | YES | KAIKENE* | | * | 128.0 | NO | | |
| 01/07/88 | DIV | NO | YES | KAIKENES* | | * | 128.0 | NO | | |
| 01/13/88 | ATB | YES | SEVERAL | TURKEY VULTURE | 1K1 | 1 | 64.5 | YES | OAK-SNH | OAK |
| 01/15/88 | ATB | NO | ONE | | | 1 | | YES | | SLN |
| 01/16/88 | NONE | NO | | | | 1 | | YES | LAX-SAN | |
| 01/22/88 | DIV | NO | SEVERAL | DOVE* | | 1 | | YES | | JAX |
| 02/03/88 | NONE | NO | NO . | DOVE* | | 1 | | NO | HRE-BUQ | BUQ |
| 02/11/88 | NONE | NO | NO | | | 1 | | YES | | |
| 02/15/88 | NONE | NO | ONE | SWALLOW* | | 1 | | NO | KAB-WKM | KAB |
| 02/16/88 | ATB | | FLOCK | CROW* | | 1 | | NO | | |
| 02/18/88 | NONE | NO | FLOCK | HOUSE MARTIN | 18Z69 | 1 | 0.6 | NO | HRE-MSV | MSV |
| 02/18/88 | NONE | NO | FLOCK | HOUSE MARTIN | 18Z69 | 2 | 0.6 | NO | HRE-MSV | MSV |
| 02/22/88 | NONE | NO | SEVERAL | SNOW GOOSE | 2J26 | 2 | 88.0 | YES | | HOU |
| 02/22/88 | NONE | NO | NO | SPARROW* | | 1 | | YES | | FHA |
| 03/04/88 | NONE | NO | NO | LAPWING | 5N1 | 1 | 7.7 | NO | | LBG |
| 03/05/88 | NONE | NO | NO | | | 1 | | YES | | PDX |
| 03/09/88 | ATO | NO | NO | | | 1 | | YES | | ISP |
| 03/10/88 | NONE | YES | SEVERAL | SPARROW* | | 1 | | YES | DEN-ASE | ASE |
| 03/14/88 | NONE | NO | SEVERAL | WOOD PIGEON | 2P9 | 1 | 18.0 | NO | | |
| 03/22/88 | NONE | NO | ONE | RING BILLED GULL | 14N12 | 1 | 16.0 | NO | | CYY |
| 03/22/88 | ATO | NO | ONE | GRAY PARTRIDGE | 4L85 | 1 | 14.0 | NO | | |
| 03/23/88 | NONE | YES | YES | AMERICAN WIGEON | 2J71 | 1 | 28.0 | YES | | HON |
| 03/25/88 | NONE | | NO | SPARROW* | | 1 | | NO | BEJ-LAN | |
| 03/29/88 | NONE | YES | YES | | | 1 | | NO | | |
| 04/04/88 | ATO | NO | NO | CANADA GOOSE | 2J30 | 2 | 128.0 | YES | | PWK |
| 04/09/88 | ATB | NO | TWO | IMMATURE COMMON LOON | 1E3 | 1 | 102.0 | YES | | |
| 04/12/88 | NONE | NO | SEVFRAL | GULL* | | 1 | 12.0 | YES | | |
| 04/18/88 | NONE | NO | YES | QUELTENE* | | 1 | 96.0 | NO | | |
| 04/24/88 | NONE | NO | NO | | | 1 | | YES | | PUR |
| 04/25/88 | | | | | | 1 | | YES | | |
| 04/27/88 | NONE | NO | | COMMON GALLINULES | 7M112 | 1 | 10.7 | YES | | IRD |
| 05/01/88 | | | | | | 1 | | YES | | |
| 05/02/88 | NONE | NO | SEVERAL | DUCK* | | 1 | | NO | YXD-YMM | YMM |
| 05/03/88 | ATB | NO | YES | | | 1 | | YES | | SBP |
| 05/04/88 | NONE | YES | FLOCK | SPOTTED DOVE | 2P65 | 1 | 5.5 | NO | | SSL |
| 05/05/88 | NONE | NO | NO | | | 1 | | YES | | |
| 05/10/88 | NONE | | | | | 1 | | YES | SMF-SNA | |
| 05/20/88 | DIV | NO | ONE | COMMON SWIFT | 1U55 | 1 | 1.5 | NO | | STR |
| 05/27/88 | NONE | NO | YES | SEAGULL* | | 1 | | NO | | CYY |
| 05/30/88 | NONE | NO | | | | 1 | | YES | SFO-SNA | |
| 06/04/88 | NONE | NO | YES | KILLDEER | 5N33 | 1 | 3.0 | YES | | |
| 06/08/88 | NONE | NO | NO | | | 1 | | YES | | BNA |
| 06/11/88 | NONE | NO | NO | NEW WORLD FRUIT BAT | SEE REMAR | 1 | 0.5 | NO | | |
| 06/20/88 | NONE | YES | SEVERAL | BLACK CROWNED PLOVER* | | 1 | 40.0 | NO | FTV-HRE | HRE |
| 06/20/88 | NONE | NO | NO | | | 1 | | NO | | MM |
| 06/20/88 | ATB | NO | NO | | | 1 | | NO | | |
| 06/27/88 | NONE | NO | ONE | BARN OWL | 1S2 | 1 | 11.3 | YES | | |
| 06/30/88 | NONE | NO | NO | | | 1 | | NO | | |
| 07/01/88 | NONE | NO | YES | AMERICAN KESTREL | 5K26 | 1 | 4.0 | NO | | CY |
| 07/05/88 | NONE | NO | FLOCK | STARLING* | | 1 | 8.0 | YES | | DA |
| 07/05/88 | NONE | NO | ONE | STARLING* | | 1 | 8.0 | YES | | DA |
| 07/06/88 | ATB | NO | SEVERAL | GULL* | | 1 | 34.0 | NO | | MU |
| 07/11/88 | NONE | NO | | KILLDEER | 5N33 | 1 | 3.0 | YES | | |
| 07/12/88 | | | | SWIFT | 1U52 | 1 | 2.0 | NO | | |
| 07/15/88 | NONE | NO | | BARN SWALLOW | 18Z37 | 1 | 0.8 | YES | | FW |

| LO | 02_1 | US_INCID | CTY_PRS | AIRPORT | LOCALE | REMARKS |
|---|---|---|---|---|---|---|
| CC | 7.7 | NO | | | COVENTRY, ENGLAND | BYPASS+CORE INLET STATORS, LPC BLDS BENT |
| CC | 7.7 | NO | | | COVENTRY, ENGLAND | GUN + VEHICLE BIRD CONTROL |
| CC | 7.7 | NO | | | COVENTRY, ENGLAND | GUN + VEHICLE BIRD CONTROL |
| RI | | YES | | | RICHMOND, VA-BYRD FIELD | FOUR FAN BLADES DAMAGED, 1 AT ROOT |
| FF | 8.0 | NO | | FDH | FRIEDRICHSHAFEN, GERMANY | 1 STG IMP BLDS BENT |
| FF | 8.0 | NO | | FDH | FRIEDRICHSHAFEN, GERMANY | IMP SLIGHTLY DAMAGED |
| CI | | NO | | | CRICIUMA, SOUTHERN BRAZIL | SIX F BLDS TIPS BENT, LPC DAMAGE |
| US | 128.0 | NO | | | USHUAIA, ARGENTINA | 6 FAN BLADES BENT AND BROKEN |
| US | 128.0 | NO | | | USHUAIA, ARGENTINA | 16 FAB BLADES BENT AND BROKEN |
| S | 64.5 | YES | OAK-SNA | OAK | SAN FRANSICO, OAK., CA | ALL COMP STAGES DAMAGED, ENG FLAMED OUT |
| S | | YES | | SLN | SALINA, KS | 3 FAN BLADES BENT |
| | | YES | LAX-SAN | | CA | FOUND ON GRD INSPEC., 2 FAN BLADES BENT |
| J | | YES | | JAX | JACKSONVILLE, FL | |
| E | | NO | HRE-BUQ | BUQ | BULAWAYO, ZIMBABWE | MINOR CORE DAMAGE REMAINED IN SERVICE |
| T | | YES | | | TAMPA, FL | |
| M | | NO | KAB-WKM | KAB | MATABELELAND, AFRICA | BIRD WENT THROUGH BYPASS |
| B | | NO | | | BAGDORA, BENGAL, INDIA | TQ MOMENTARILY DROPPED BELOW 60% |
| M | 0.6 | NO | HRE-MSV | MSV | MASVINGO, ZIMBABWE | BIRD WENT THROUGH BYPASS |
| M | 0.6 | NO | HRE-MSV | MSV | MASVINGO, ZIMBABWE | ONE BIRD INTO CORE, ONE THROUGH BYPASS |
| H | 88.0 | YES | | HOU | HOUSTON, TEX | STGS 1 THRU 4,LPC+HPC BLDS NICKED |
| S | | YES | | FHA | SIERRA VISTA, AZ | |
| P | 7.7 | NO | | LBG | PARIS, FRANCE | STG 1 AND 2 IMP DAMAGE |
| P | | YES | | PDX | PORTLAND, OR | 1STG IMP BENT+1 BROKEN BLD,2STG VANE DAM |
| R | | YES | | ISP | RONKOKOMA, NY | CHG IN ENG NOISE, 2 BENT IMP BLDS |
| A | | YES | DEN-ASE | ASE | ASPEN, COL | |
| S | 18.0 | NO | | | SUFFOLK, ENGLAND | IPSWICH AIRPORT, RPM DROPPED TO 40 % |
| T | 16.0 | NO | | CYYZ | TORONTO, CANADA | |
| R | 14.0 | NO | | | RAMSTEIN AIR BASE, GERMANY | |
| H | 28.0 | YES | | HON | HURON, SD | |
| H | | NO | BEJ-LAN | | HOHHOT, CHINA | |
| I | | NO | | | ISLAMABAD, PAKISTAN | |
| H | 128.0 | YES | | PWK | WHEELING,IL | NACELLE DAM, #5 BEARING OVERLOAD |
| C | 102.0 | YES | | | CLEBURNE, TX. | N2 INCREASE,N2+TEMP DECREASE MOMENTARILY |
| H | 12.0 | YES | | | MERTLE BEACH, SC | EGT UP 20 DEG C, SEVERAL BENT F BLADES |
| F | 96.0 | NO | | | RANCAQUA, SANTIAGO, CHILE | 2-1STG IMP BLDS BENT, 1 APPROX 30 DEG |
| F | | YES | | PUR | PUEBLO, COLORADO | |
| ( | | YES | | | CA | FOUND DURING GROUND INSPECTION |
| I | 10.7 | YES | | IAD | WASHINGTON, DC-DULLES | FOUND ON GRD INSPEC, MULT AC STRIKES |
| I | | YES | | | COLORADO SPRINGS, COL | FOUND DURING GROUND INSPECTION |
| | | NO | YXD-YMM | YMM | FORT MCMURRAY, CANADA | NO ENGINE INGESTION OCCURED, GEAR IMPACT |
| | | YES | | SBP | SAN LUIS OBISPO, CA | SLIGHT 1STG+2 IMP DAM,DEBRIS IN F NOZZLE |
| | 5.5 | NO | | SSL | SINGAPORE | FAN DUCT DAMAGE |
| I | | YES | | | PENSACOLA, FL | |
| | | YES | SMF-SNA | | CA | FOUND DURING GROUND INSPECTION |
| | 1.5 | NO | | STR | STUTTGART, GERMANY | BENT F BLD HAD 1.5'' CRACK, VLNTRY IFSD |
| | | NO | | CYYZ | TORONTO, CANADA | |
| | | YES | SFO-SNA | | CA | FOUND DURING GROUND INSPECTION |
| | 3.0 | YES | | | DENVER, CO | DIFFERENT ENGINE SOUND AFTER INGESTION |
| | | YES | | BNA | NASHVILLE, TN | |
| | 0.5 | NO | | | BRAZIL | SPECIES (STENODERMATINAE) NOT IN CODES |
| | 40.0 | NO | FTV-HRE | HRE | HARARE, ZIMBABWE | |
| | | NO | | MMX | MALMOE, SWEDEN | |
| | | NO | | | LINATE, MILAN | ENGINE NOISE, ITT 20-50DEG.C ABOVE NORM |
| | 11.3 | YES | | | PALM SPRINGS, CA | ABRADABLE BEHIND FAN DAMAGED BY IMPACT |
| | | NO | | | LUTON,SCOTLAND | FOUND DURING GROUND INSPECTION |
| | 4.0 | NO | | CYYC | CALGARY, ALBERTA, CANADA | |
| | 8.0 | YES | | DAY | VANDALIA, OH | CREW TOOK EVASIVE ACTION |
| | 8.0 | YES | | DAY | VANDALIA, OH | |
| | 34.0 | NO | | MUC | MUNICH, GERMANY | |
| | 3.0 | YES | | | APPLETON, WISC | FOUND DURING GROUND INSPECTION |
| | 2.0 | NO | | | GUERNSEY CHANNEL ISLANDS | |
| | 0.8 | YES | | FWA | BAERFIELD, FT WAYNE, IND | FOUND DURING GROUND INSPECTION |

| EDATE | EVT# | ETIME | SIGN_EVT | AIRCRAFT | ENGINE | DASH | ENG_POS | DMG_CODE | SEVERITY | POW_LOSS | MAX_V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 07/16/88 | 107 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE | |
| 07/18/88 | 108 | 10:00:00 | MULT ENG | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,K | 1 | NONE | |
| 07/18/88 | 108 | 10:00:00 | MULT ENG | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE | |
| 07/19/88 | 117 | 15:00:00 | NONE | FALCON 10 | TFE731 | 2 | 2 RIGHT | | 9 | NONE | NONE |
| 07/21/88 | 118 | 20:40:00 | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | | 9 | NONE | NONE |
| 07/21/88 | 128 | 21:15:00 | MULT ENG | MU-2 | TPE331 | 6A | 1 LEFT | | 9 | NONE | NONE |
| 07/21/88 | 128 | 21:15:00 | MULT ENG | MU-2 | TPE331 | 6A | 2 RIGHT | | 9 | NONE | NONE |
| 07/25/88 | 109 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE | |
| 07/29/88 | 124 | | MULT BIRDS | LEAR 35A | TFE731 | 2 | 1 LEFT | A,D | 2 | NONE | NONE |
| 08/04/88 | 123 | 15:00:00 | OTHER | JS 31 | TPE331 | 12UAR | 2 RIGHT | A,K,P | 2 | YES | NONE |
| 08/09/88 | 143 | 15:30:00 | INV POW LOSS | DO 228 | TPE331 | 5 | 2 RIGHT | A,K | 3 | SPOOL DOWN | NONE |
| 08/09/88 | 197 | | NONE | BAE146 | ALF502 | | 4 RIGHT OUTBOARD | | 9 | | |
| 08/16/88 | 125 | 7:53:00 | MULT BIRDS | LEAR 35 | TFE731 | 2 | 2 RIGHT | A,C,K | 1 | | NONE |
| 08/22/88 | 199 | | NONE | JS 3103 | TPE331 | 10U | 1 LEFT | | 9 | | |
| 08/23/88 | 202 | | NONE | JS 3101 | TPE331 | 10U | 1 LEFT | | 9 | | |
| 08/25/88 | 129 | 17:15:00 | NONE | METRO II | TPE331 | 10UA | 1 LEFT | A,K | 3 | | SOME |
| 08/31/88 | 126 | 12:00:00 | NONE | LEAR 36A | TFE731 | 2 | 1 LEFT | A,B | 3 | NONE | NONE |
| 09/07/88 | 133 | 19:35:00 | MULT ENG | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE | |
| 09/07/88 | 133 | 19:35:00 | MULT ENG | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE | |
| 09/13/88 | 127 | 17:00:00 | MULT BIRDS | CITATION 3 | TFE731 | 3BR | 2 RIGHT | A,C,K | 1 | YES | NONE |
| 09/15/88 | 134 | | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | | 9 | NONE | |
| 09/15/88 | 135 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE | |
| 09/22/88 | 130 | 13:36:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | A,L | 9 | NONE | NONE |
| 09/22/88 | 137 | | NONE | CL600 | ALF502 | L-2C | 1 LEFT | | 9 | NO | |
| 09/23/88 | 144 | 9:48:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | | 4 | 10% TORQUE L | NONE |
| 09/24/88 | 131 | 9:42:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | | 9 | NONE | NONE |
| 09/27/88 | 132 | 8:30:00 | NONE | CESSNA 500 | JT15D | 1A | 1 LEFT | | 9 | NONE | |
| 09/29/88 | 145 | 5:30:00 | NONE | SA26 | TPE331 | 1 | 2 RIGHT | | 9 | SMALL | HIGH |
| 09/30/88 | 155 | 9:30:00 | NONE | METRO III | TPE331 | 11 | 1 LEFT | A,K | 3 | NONE | NONE |
| 10/06/88 | 201 | | NONE | JS 3101 | TPE331 | 10U | 1 LEFT | | 9 | | |
| 10/08/88 | 141 | 8:20:00 | MULT BIRDS | FALCON 50 | TFE731 | 3 | 2 CENTER | A,D,P | 2 | NONE | SOME |
| 10/11/88 | 142 | 23:00:00 | NONE | BAE125-700 | TFE731 | 3 | 2 RIGHT | | 9 | NONE | NONE |
| 10/15/88 | 163 | 10:30:00 | NONE | FALCON 10 | TFE731 | 2 | 1 LEFT | A,D | 2 | NONE | NONE |
| 10/19/88 | 203 | | NONE | JS 3101 | TPE331 | 10U | 1 LEFT | | 9 | | |
| 10/20/88 | 157 | | NONE | COMM 6900 | TPE331 | 5 | 1 LEFT | A,P | 3 | | |
| 10/20/88 | 160 | 14:00:00 | NONE | BAE 125 | TFE731 | 3 | 2 RIGHT | A,B,K | 1 | | SOME |
| 10/22/88 | 138 | 2:00:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | A,P | 4 | NONE | |
| 10/22/88 | 139 | 8:30:00 | NONE | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | A,C | 3 | N1 CHANGE | |
| 10/22/88 | 156 | 7:00:00 | MULT BIRDS | JS 3101 | TPE331 | 10UG | 2 RIGHT | A,K | 4 | YES | SOME |
| 10/26/88 | 136 | 12:20:00 | NONE | S211 | JT15D | 4C | 2 CENTER | | 9 | NONE | NONE |
| 10/26/88 | 168 | | NONE | FALCON 50 | TFE731 | 3 | 3 RIGHT | A,K,P | 1 | NONE | NONE |
| 10/27/88 | 146 | 19:20:00 | NONE | BAE146 | ALF502 | R3A | 1 LEFT OUTBOARD | | 9 | NONE | NONE |
| 10/29/88 | 140 | 13:28:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE | |
| 10/29/88 | 161 | 23:00:00 | NONE | WESTW 1124 | TFE731 | 3 | 2 RIGHT | A,D | 2 | | NONE |
| 11/03/88 | 164 | 7:00:00 | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | A,C | 3 | | NONE |
| 11/08/88 | 158 | | NONE | METRO | TPE331 | 11U | 2 RIGHT | A,K | 3 | NONE | NONE |
| 11/09/88 | 165 | 18:15:00 | NONE | FALCON 50 | TFE731 | 3 | 1 LEFT | | 9 | NONE | NONE |
| 11/10/88 | 169 | | NONE | JETSTAR | TFE731 | 3 | 3 RIGHT INBOARD | A | 4 | | NONE |
| 11/13/88 | 166 | | NONE | LEAR 35 | TFE731 | 2 | 1 LEFT | | 9 | NONE | NONE |
| 11/21/88 | 167 | 7:45:00 | MULT BIRDS | WESTW 1124 | TFE731 | 3 | 1 LEFT | A,D | 2 | NONE | NONE |
| 11/21/88 | 171 | 15:00:00 | NONE | LEAR 35 | TFE731 | 2 | 2 RIGHT | A | 4 | NONE | NONE |
| 11/28/88 | 147 | | NONE | BAE146-QT | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE | |
| 11/28/88 | 159 | 8:00:00 | NONE | JS 31 | TPE331 | 10UG | 2 RIGHT | A | 4 | NONE | SOME |
| 11/29/88 | 148 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE | |
| 12/01/88 | 149 | 14:00:00 | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | A,C | 3 | NONE | NONE |
| 12/02/88 | 150 | | MULT BIRDS | BAE146 | ALF502 | R3A | 3 RIGHT INBOARD | | 9 | NONE | NONE |
| 12/16/88 | 151 | | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE | |
| 12/18/88 | 172 | 17:30:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | A,K | 3 | YES | NONE |
| 12/21/88 | 153 | 13:00:00 | NONE | T-47 | JT15D | 5 | 2 RIGHT | A,D,K,P | 1 | | HIGH |
| 12/22/88 | 152 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,C,P | 3 | NONE | |
| 12/22/88 | 154 | 6:00:00 | NONE | DIAMOND 1A | JT15D | 4D | 1 LEFT | A,G | 2 | | SOME |
| 12/28/88 | 173 | 16:00:00 | NONE | CESSNA 551 | JT15D | 4 | 2 RIGHT | A,G,P | 2 | NONE | |

| IOE | SEVERITY | POW_LOSS | MAX_VIBE | THROTTLE | IFSD | POF | ALTITUDE | SPEED | FL_RULES | LT_CONDS | WEATHER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 1 | NONE | | | NO | LANDING | | 210 | IFR | DARK | DRIZZLE |
| | 9 | NONE | | | NO | LANDING | | 210 | IFR | DARK | DRIZZLE |
| | 9 | NONE | NONE | NONE | NO | LANDING | 0 | 50 | | LIGHT | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | UNKNOWN | 980 | 120 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | | | IFR | DARK | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | | | IFR | DARK | SCATTERED |
| | 4 | NONE | | | NO | UNKNOWN | | | | LIGHT | CLEAR |
| | 2 | NONE | NONE | NONE | NO | LANDING | | | IFR | LIGHT | CLEAR |
| | 2 | YES | NONE | NONE | NO | APPROACH | 200 | 120 | VFR | LIGHT | BROKEN |
| | 3 | SPOOL DOWN | NONE | CUTOFF | INVOLUNTA | APPROACH | 200 | 105 | VFR | LIGHT | CLEAR |
| | 9 | | | | | UNKNOWN | | | | | |
| | 1 | | NONE | RETARD | NO | TAKEOFF | 0 | 120 | IFR | LIGHT | SCATTERED |
| | 9 | | | | | APPROACH | | | | | |
| | 9 | | | | | UNKNOWN | | | | | |
| | 3 | | SOME | | NO | TAKEOFF | 0 | 95 | VFR | LIGHT | CLEAR |
| | 3 | NONE | NONE | NONE | NO | TAKEOFF | 3 | 120 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | | NO | TAKEOFF | | | | DARK | |
| | 9 | NONE | | | NO | TAKEOFF | | | | DARK | |
| | 1 | YES | NONE | | NO | TAKEOFF | 50 | 130 | | LIGHT | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | NONE | NONE | | NO | APPROACH | 100 | 125 | VFR | LIGHT | CLEAR |
| | 9 | NO | | | NO | UNKNOWN | | | | | |
| | 4 | 10% TORQUE L | NONE | | NO | TAKEOFF | 0 | 101 | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | | NO | APPROACH | 200 | 125 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | UNKNOWN | | | VFR | LIGHT | CLEAR |
| | 9 | SMALL | HIGH | CUTOFF | OTHER | TAKEOFF | | 97 | VFR | DARK | CLEAR |
| | 3 | NONE | NONE | NONE | NO | APPROACH | | | VFR | LIGHT | SCATTERED |
| | 9 | | | | | UNKNOWN | | | | | |
| | 2 | NONE | SOME | CUTOFF | OTHER | CLIMB | 1150 | 170 | IFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | NONE | NO | TAKEOFF | 30 | 150 | VFR | DARK | OVERCAST |
| | 2 | NONE | NONE | RETARD | NO | TAKEOFF | 0 | 100 | VFR | LIGHT | CLEAR |
| | 9 | | | | | UNKNOWN | | | | | |
| | 3 | | | | NO | APPROACH | | | | | |
| | 1 | | SOME | RETARD | | CLIMB | 700 | 160 | VFR | LIGHT | CLEAR |
| | 4 | NONE | | NONE | NO | UNKNOWN | | | | DARK | OVERCAST |
| | 3 | N1 CHANGE | | NONE | NO | TAKEOFF | | 180 | IFR | LIGHT | FOG |
| | 4 | YES | SOME | CUTOFF | VOLUNTARY | TAKEOFF | 50 | 120 | VFR | DAWN | SCATTERED |
| | 9 | NONE | NONE | NONE | NO | UNKNOWN | | | VFR | LIGHT | CLEAR |
| | 1 | NONE | NONE | | NO | TAXI | 0 | 0 | | LIGHT | CLEAR |
| | 9 | NONE | NONE | | NO | TAXI | 0 | 0 | VFR | DARK | CLEAR |
| | 9 | NONE | | | NO | APPROACH | 200 | 110 | | LIGHT | CLEAR |
| | 2 | | NONE | IDLE | NO | TAKEOFF | 0 | 120 | VFR | DARK | OVERCAST |
| | 3 | | NONE | IDLE | NO | LANDING | 10 | 125 | VFR | DAWN | SCATTERED |
| | [illegible] | NONE | NONE | | NO | UNKNOWN | | | | | |
| | 9 | NONE | NONE | NONE | NO | APPROACH | 1100 | 180 | IFR | DUSK | CLEAR |
| | 4 | | NONE | | NO | UNKNOWN | | | | | |
| | 9 | NONE | NONE | NONE | NO | APPROACH | | | VFR | DAY | CLEAR |
| | 2 | NONE | NONE | NONE | NO | TAKEOFF | 10 | 140 | VFR | LIGHT | SCATTERED |
| | 4 | NONE | NONE | NONE | NO | LANDING | 100 | 150 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | UNKNOWN | | | | | |
| | 4 | NONE | SOME | NONE | NO | APPROACH | 300 | 130 | VFR | LIGHT | CLEAR |
| | 9 | NONE | | NONE | NO | UNKNOWN | | | | | |
| | 3 | NONE | NONE | NONE | NO | APPROACH | | | IFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | RETARD | NO | LANDING | 0 | 110 | IFR | DARK | DRIZZLE |
| | 9 | NONE | | NONE | NO | UNKNOWN | | | | | |
| | 3 | YES | NONE | NONE | NO | TAKEOFF | 250 | 120 | | DUSK | OVERCAST |
| | 1 | | HIGH | IDLE | NO | CRUISE | 1900 | 320 | IFR | LIGHT | OVERCAST |
| | 3 | NONE | | | NO | UNKNOWN | | | | LIGHT | |
| | 2 | | SOME | RETARD | NO | TAKEOFF | 0 | 120 | VFR | DARK | SCATTERED |
| | 2 | NONE | | IDLE | NO | TAKEOFF | 0 | 100 | IFR | LIGHT | FOG |

| EDATE | EVT# | CREW_AC | CREW_AL | BIRD_SEE | BIRD_NAM | BIRD_SPE | #_BIRDS | WT_OZ_1 | US_INCID | CTY_PRS | AIRPORT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 07/16/88 | | NONE | NO | | KILLDEER | 5N33 | 1 | 3.0 | YES | | FWS |
| 07/18/88 | | | YES | | KILLDEER | 5N33 | 1 | 3.0 | YES | CRW-ORD | ORD |
| 07/18/88 | | | YES | | LESSER YELLOWLEGS | 6N20 | 1 | 3.0 | YES | CRW-ORD | ORD |
| 07/19/88 | | NONE | NO | NO | EURASIAN KESTREL | 5K27 | 1 | 8.0 | NO | | LBG |
| 07/21/88 | | NONE | NO | YES | | | 1 | | YES | | PTK |
| 07/21/88 | | NONE | NO | NO | GRAY FACED BUZZARD* | | | 14.0 | NO | | |
| 07/21/88 | | NONE | NO | NO | GRAY FACED BUZZARD* | | | 14.0 | NO | | |
| 07/25/88 | | NONE | NO | | AMERICAN KESTREL | 5K26 | 1 | 3.5 | YES | ORD-FWA | |
| 07/29/88 | | NONE | NO | NO | GULL* | | * | | NO | | |
| 08/04/88 | | NONE | YES | FLOCK | WOOD PIGEON* | | 1 | 24.0 | NO | | |
| 08/09/88 | | NONE | NO | ONE | SEAGULL* | | 1 | 24.0 | NO | | GWT |
| 08/09/88 | | | | | | | 1 | | YES | | |
| 08/16/88 | | NONE | | | GULL* | | * | | NO | | LDK |
| 08/22/88 | | | | | | | 1 | | YES | | PHL |
| 08/23/88 | | | | | | | 1 | | YES | | |
| 08/25/88 | | ATO | NO | ONE | | | 1 | | YES | | TUP |
| 08/31/88 | | ATB | NO | ONE | GULL* | | 1 | | NO | | NCE |
| 09/07/88 | | ATB | YES | SEVERAL | HORNED LARK | 17Z74 | 1 | 1.5 | YES | | ROA |
| 09/07/88 | | ATB | YES | SEVERAL | HORNED LARK | 17Z74 | 1 | 1.5 | YES | | ROA |
| 09/13/88 | | NONE | NO | SEVERAL | ROCK DOVE | 2P1 | 2 | 14.0 | YES | | BUR |
| 09/15/88 | | NONE | NO | NO | | | 1 | | YES | | |
| 09/15/88 | | | | NO | | | 1 | | YES | | FWA |
| 09/22/88 | | NONE | NO | NO | GULL* | | 1 | | YES | | YKM |
| 09/22/88 | | NONE | NO | NO | | | 1 | | YES | | |
| 09/23/88 | | NONE | NO | YES | HORNED LARK | 17Z74 | 1 | 1.5 | YES | | TUP |
| 09/24/88 | | NONE | NO | ONE | SPARROW OR STARLING* | | 1 | | YES | | PDX |
| 09/27/88 | | NONE | NO | NO | | | 1 | | YES | CCR-SMF | CCR |
| 09/29/88 | | | NO | ONE | OWL* | | 1 | 64.0 | YES | | DEN |
| 09/30/88 | | NONE | | ONE | GULL* | | 1 | | YES | | SBA |
| 10/06/88 | | | | | | | 1 | | YES | | |
| 10/03/88 | | NONE | NO | ONE | CORMORAN* | | 4 | | NO | | NCE |
| 10/11/88 | | ATB | NO | NO | AMERICAN WOODCOCK | 6N37 | 1 | 6.0 | YES | | PHL |
| 10/15/88 | | ATO | NO | SEVERAL | HAWK* | | 1 | 32.0 | NO | | EDLP |
| 10/19/88 | | | | | | | 1 | | YES | | |
| 10/20/88 | | | | YES | | | 1 | | NO | | |
| 10/20/88 | | ATB | NO | FLOCK | RING-BILLED GULL | 14N12 | 1 | 16.0 | YES | | CCR |
| 10/22/88 | | NONE | NO | NO | | | 1 | | NO | NUR-KOL | BNJ |
| 10/22/88 | | OTHER | NO | NO | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | LAX-FAT | LAX |
| 10/22/88 | | ATB | NO | SEVERAL | GULL* | | 2 | | YES | | BOR |
| 10/26/88 | | NONE | NO | NO | | | 1 | | NO | | |
| 10/26/88 | | | NO | NO | SONG THRUSH | 412282 | 1 | 2.5 | NO | | TRN |
| 10/27/88 | | NONE | NO | NO | | | 1 | | NO | SNG-JAK | JAK |
| 10/29/88 | | NONE | | | | | 1 | | YES | CRW-ROA | ROA |
| 10/29/88 | | ATO | NO | NO | GULL* | | 1 | | NO | | TLV |
| 11/03/88 | | NONE | NO | NO | GULL* | | 1 | 64.0 | YES | | |
| 11/08/88 | | NONE | NO | NO | | | 1 | | YES | | |
| 11/09/88 | | NONE | NO | NO | | | 1 | | YES | | HPN |
| 11/10/88 | | NONE | NO | NO | MEADOW LARK | 64Z67 | 1 | 3.0 | YES | | |
| 11/13/88 | | NONE | NO | YES | KILLDEER | 5N33 | 1 | 3.0 | YES | | |
| 11/21/88 | | ATB | NO | FLOCK | RING-BILLED GULL | 14N12 | 3 | 17.0 | YES | | HNO |
| 11/21/88 | | NONE | NO | YES | | | 1 | | NO | | SYD |
| 11/28/88 | | NONE | NO | NO | | | 1 | | NO | | |
| 11/28/88 | | NONE | NO | NO | GULL* | | 1 | | YES | | PDX |
| 11/29/88 | | NONE | | NO | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | IAD-MLB | |
| 12/01/88 | | NONE | NO | NO | | | 1 | | YES | RNO-SFO | SFO |
| 12/02/88 | | NONE | NO | FLOCK | COMMON LAPWING | 5N1 | * | 7.7 | NO | FBU-NCL | NCL |
| 12/16/88 | | NONE | NO | NO | LONGEARED OWL | 2S120 | 1 | 10.0 | NO | -PWK | |
| 12/18/88 | | ATB | NO | NO | | | 1 | | YES | | DAY |
| 12/21/88 | | DIV | NO | NO | LESSER SCAUP | 2J125 | 1 | 16.0 | YES | | |
| 12/22/88 | | | | | | | 1 | | NO | EDI-ABR | |
| 12/22/88 | | OTHER | NO | NO | | | 1 | | YES | KY-LA | |
| 12/28/88 | | ATO | NO | SEVERAL | GULL* | | 1 | | NO | RON-C1A | RON |

| DS | WT_OZ_1 | US_INCID | CTY_PRS | AIRPORT | LOCALE | REMARKS |
|---|---|---|---|---|---|---|
| 1 | 3.0 | YES | | FWS | BAERFIELD, FT WAYNE, IND | FOUND DURING GROUND INSPECTION |
| 1 | 3.0 | YES | CRW-ORD | ORD | CHICAGO, ILL-OHARE | SEVERAL 1ST STG COMP BLDS BENT |
| 1 | 3.0 | YES | CRW-ORD | ORD | CHICAGO, ILL-OHARE | |
| 1 | 8.0 | NO | | LBG | LE BOURGET, FRANCE | |
| 1 | | YES | | PTK | PONTIAC, MI | |
| | 14.0 | NO | | | MIYAKO, JAPAN | |
| | 14.0 | NO | | | MIYAKO, JAPAN | TORQUE DROPPED 6% THEN RECOVERED |
| 1 | 3.5 | YES | ORD-FWA | | ILL-IND | FOUND DURING GROUND INSPECTION |
| * | | NO | | | MILANO-LINATE, ITALY | |
| 1 | 24.0 | NO | | | CAMBELL TOWN, UK | 1 IMP BLD FAILED, 3 IMP BLDS BENT |
| 1 | 24.0 | NO | | GWT | WESTERLAND, GERMANY | 2-1STG IMP BLDS BENT, DEBRIS IN F NOZZLE |
| 1 | | YES | | | CHICAGO, IL | FOUND ON GRD INSPEC, DEBRIS ON INTAKE |
| * | | NO | | LDK | LINDKOPING, SWEDEN | |
| 1 | | YES | | PHL | PHILA, PA | |
| 1 | | YES | | | | ENGINE REMOVED FOR INSPEC, BENT PROP TIP |
| 1 | | YES | | TUP | TUPELO, MS | 1-1STG IMP BLD BENT |
| 1 | | NO | | NCE | NICE, FRANCE | 1 FAN BLADE LE CORNER SLIGHTLY BENT |
| 1 | 1.5 | YES | | ROA | ROANOKE, VA | |
| 1 | 1.5 | YES | | ROA | ROANOKE, VA | |
| 2 | 14.0 | YES | | BUR | BURBANK, CA | 3 BENT F BLADES,6 DAMAGED CORE STATORS |
| 1 | | YES | | | WASHINGTON, D.C. | FOUND DURING GROUND INSPECTION |
| 1 | | YES | | FWA | FT. WAYNE, IND | FOUND DURING GROUND INSPECTION |
| 1 | | YES | | YKM | YAKIMA, WA | COWLING DAMAGE |
| 1 | | YES | | | TETERBORO, NJ | |
| 1 | 1.5 | YES | | TUP | TUPELO, MISS | EGT RISE |
| 1 | | YES | | PDX | PORTLAND, OR | |
| 1 | | YES | CCR-SMF | CCR | CONCORD, CA | FOUND DURING GROUND INSPECTION AT SMF |
| 1 | 64.0 | YES | | DEN | DENVER, CO | PRECAUTIONARY SHUTDOWN, PROP SPIN DAMAGE |
| 1 | | YES | | SBA | SANTA BARBARA, CA | BENT IMP BLDS |
| 1 | | YES | | | DAYTON, OH | FOUND ON GRD INSPEC |
| 4 | | NO | | NCE | NICE, FRANCE | PRECAUTIONARY IFSD, FAN STATOR DAMAGE |
| 1 | 6.0 | YES | | PHL | PHILA, PA | |
| 1 | 32.0 | NO | | EDLP | PADERBORN, GERMANY | 12 FAN BLADES BENT |
| 1 | | YES | | | BALTIMORE, MD | FOUND ON GRD INSPEC |
| 1 | | NO | | | HOHENEMS, AUSTRIA | |
| 1 | 16.0 | YES | | CCR | CONCORD, CA | 8 F BLDS TIP CURL,COMP STATOR VANES TORN |
| 1 | | NO | NUR-KOL | BNJ | BONN, WEST GERMANY | FOUND ON GRD,ONE DISTORTED FAN EXIT VANE |
| 1 | 4.0 | YES | LAX-FAT | LAX | LOS ANGELES, CA | N1 HUNTING APPROXIMATELY 2% |
| 2 | | YES | | BDR | BRIDGEPORT, CT | INTAKE COWLING AND PROP DAMAGED |
| 1 | | NO | | | PAYA LEBAR, SINGAPORE | FOUND ON GRD INSPECTION, ENGINE REMOVED |
| 1 | 2.5 | NO | | TRN | TORINO, ITALY | AM EVENT, COMP STATOR VANES BENT |
| 1 | | NO | SNG-JAK | JAK | JAKARTA, INDONESIA | SMALL BIRD |
| 1 | | YES | CRW-ROA | ROA | ROANOKE, VA | |
| 1 | | NO | | TLV | LOD, ISRAEL | |
| 1 | 64.0 | YES | | | SCHENECTADY, NY | |
| 1 | | YES | | | SAN FRANCISCO, CA | 1 BENT DIFFUSER VANE |
| 1 | | YES | | HPN | WESTCHESTER, NY | |
| 1 | 3.0 | YES | | | | |
| 1 | 3.0 | YES | | | MONTEREY, CA | CABIN DOOR |
| 3 | 17.0 | YES | | HNO | BEDFORD, MA | |
| 1 | | NO | | SYD | SYDNEY, AUSTRALIA | |
| 1 | | NO | | | AYRESHIRE, SCOTLAND | FOUND DURING INSPECTION |
| 1 | | YES | | PDX | PORTLAND, OR | |
| 1 | 4.0 | YES | IAD-MLB | | WASHINGTON, DC | FOUND DURING GROUND INSPECTION |
| 1 | | YES | RNO-SFO | SFO | SAN FRANCISCO, CA | 2 BENT FAN BLADES |
| * | 7.7 | NO | FBU-NCL | NCL | NEWCASTLE, ENGLAND | |
| 1 | 10.0 | NO | -PWK | | PRESTWICK, SCOTLAND | FOUND DURING GROUND INSPECTION |
| 1 | | YES | | DAY | VANDALIA, OH | 1-1STG IMP BLD BENT, COMB LINER CRACKED |
| 1 | 16.0 | YES | | | ENGLAND AFB, LA | 5 DIFFUSERS DAMAGED, MINOR IMPELLOR DMG |
| 1 | | NO | EDI-ABR | | ABERDEEN, SCOTLAND | 1 FAN BLADE + 4 EXIT GUIDE VANES BENT |
| 1 | | YES | KY-LA | | OWENSBURO, LA | 3 FBLDS LE TIP CORNERS LIB APPROX. 1"X1" |
| 1 | | NO | RON-CIA | RON | RONDON, COLOMBIA | FALCONRY BIRD CONTROL |

| EDATE | EVT# | ETIME | SIGN_EVT | AIRCRAFT | ENGINE | DASH | ENG_POS | DMG_CODE | SEVERITY | POW_LOSS |
|---|---|---|---|---|---|---|---|---|---|---|
| 01/02/89 | 177 | 14:00:00 | NONE | BAE125 | TFE731 | 3 | 1 LEFT | A,D | 2 | |
| 01/08/89 | 170 | 16:00:00 | NONE | LEAR 35A | TFE731 | 2 | 1 LEFT | A,D,P | 2 | NONE |
| 01/29/89 | 185 | | NONE | METRO | TPE331 | 3U | 2 RIGHT | A,K | 3 | NONE |
| 01/30/89 | 178 | 12:00:00 | NONE | WESTWIND | TFE731 | 3 | 2 RIGHT | A | 4 | NONE |
| 02/07/89 | 175 | 11:44:00 | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE |
| 02/21/89 | 179 | 16:10:00 | NONE | BAE125-800 | TFE731 | 5R | 2 RIGHT | | 9 | NONE |
| 02/22/89 | 174 | 16:30:00 | NONE | CESSNA 550 | JT15D | 4 | UNK | | 9 | |
| 02/28/89 | 176 | 18:01:00 | MULT BIRDS | BAE146 | ALF502 | R5 | 2 LEFT INBOARD | A,K,L | 1 | COMPRESS |
| 03/06/89 | 180 | | NONE | BAE146 | ALF502 | R5 | 4 RIGHT OUTBOARD | | 9 | NONE |
| 03/07/89 | 181 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 03/16/89 | 182 | | NONE | BAE146 | ALF502 | R5 | | | 9 | |
| 03/16/89 | 186 | | NONE | LEAR 35A | TFE731 | 2 | | A,D,K,P | 1 | |
| 03/17/89 | 183 | 15:15:00 | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | COMPRESS |
| 03/20/89 | 187 | 12:30:00 | NONE | LEAR 55 | TFE731 | 3A | 1 LEFT | A | 4 | NONE |
| 03/21/89 | 184 | 13:00:00 | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | A,K | 1 | NONE |
| 03/24/89 | 191 | | NONE | | TFE731 | | | | 9 | |
| 03/24/89 | 192 | | NONE | | TFE731 | | | | 9 | |
| 04/02/89 | 198 | 15:30:00 | NONE | FAIRCHILD | TPE331 | 11 | | A | 4 | |
| 04/07/89 | 193 | 14:15:00 | NONE | METRO | TPE331 | 11U | 1 LEFT | A | 4 | YES |
| 04/10/89 | 194 | | NONE | JS 3101 | TPE331 | .JUF | 1 LEFT | | 9 | NONE |
| 04/12/89 | 189 | | NONE | BAE146 | ALF502 | R5 | 3 RIGHT INBOARD | | 9 | NONE |
| 04/13/89 | 195 | 18:30:00 | NONE | COMM | TPE331 | 5 | 2 RIGHT | A | 4 | YES |
| 04/26/89 | 190 | | NONE | BAE146 | ALF502 | R5 | 1 LEFT OUTBOARD | | 9 | NONE |
| 04/26/89 | 196 | 10:00:00 | NONE | JS 3101 | TPE331 | 10UG | 1 LEFT | A | 4 | YES |

| ING_CODE | SEVERITY | POW_LOSS | MAX_VIBE | THROTTLE | IFSD | POF | ALTITUDE | SPEED | FL_RULES | LT_CONDS | WEATHER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.D | 2 | | | | NO | TAKEOFF | 50 | | VFR | | BROKEN |
| 1.D,P | 2 | NONE | NONE | RETARD | NO | TAKEOFF | 30 | 160 | VFR | LIGHT | OVERCAST |
| 1.K | 3 | NONE | NONE | | NO | LANDING | | | | | |
| 1 | 4 | NONE | NONE | RETARD | NO | TAKEOFF | 50 | | VFR | LIGHT | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | | LIGHT | CLEAR |
| | 9 | NONE | NONE | | NO | APPROACH | 800 | 250 | VFR | LIGHT | CLEAR |
| | 9 | | | | NO | TAKEOFF | | | | DAY | |
| 1.K.L | 1 | COMPRESSOR | | | NO | APPROACH | 800 | 170 | | DUSK | |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | NONE | | | NO | UNKNOWN | | | | | |
| | 9 | | | | NO | UNKNOWN | | | | | |
| 1.D.K,P | 1 | | | | YES | UNKNOWN | | | | | |
| | 9 | COMPRESSOR | | IDLE | NO | APPROACH | 50 | 110 | VFR | LIGHT | CLEAR |
| 1 | 4 | NONE | NONE | | NO | APPROACH | 1400 | 140 | VFR | LIGHT | CLEAR |
| 1.K | 1 | NONE | | | NO | UNKNOWN | | | VFR | LIGHT | CLEAR |
| | 9 | | | | | UNKNOWN | | | | | |
| | 9 | | | | | UNKNOWN | | | | | |
| 1 | 4 | | | | | TAKEOFF | | | | | |
| 1 | 4 | YES | | | NO | CLIMB | 300 | | VFR | LIGHT | CLEAR |
| | 9 | NONE | NONE | | NO | UNKNOWN | | | IFR | LIGHT | CLOUDY |
| | 9 | NONE | | | NO | UNKNOWN | | | | LIGHT | |
| 1 | 4 | YES | NONE | | YES | LANDING | 25 | 105 | VFR | DUSK | CLEAR |
| | 9 | NONE | | | NO | UNKNOWN | | | IFR | LIGHT | CLEAR |
| H | 4 | YES | NONE | | NO | TAKEOFF | 100 | 120 | IFR | LIGHT | OVERCAST |

| EDATE | EVT# | CREW_AC | CREW_AL | BIRD_SEE | BIRD_NAM | BIRD_SPE | #_BIRDS | WT_OZ_1 | US_INCID | CTY_PRS | AIRPORT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/02/89 | | DIV | | | GULL* | | 1 | | NO | | |
| 01/08/89 | | ATB | NO | ONE | BUZZARD* | | 1 | | NO | | GIG |
| 01/29/89 | | | | | MAGPIE* | | 1 | 40.0 | NO | | |
| 01/30/89 | | ATB | NO | YES | ROCK DOVE | 2P1 | 1 | 14.0 | YES | | SHV |
| 02/07/89 | | | | | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | | ORD |
| 02/21/89 | | NONE | NO | YES | GULL* | | 1 | | NO | | |
| 02/22/89 | | NONE | | | | | 1 | | YES | TX-OK | TX |
| 02/28/89 | | | YES | FLOCK | SNOW GOOSE | 2J26 | * | 88.0 | YES | SNA-SMF | SMF |
| 03/06/89 | | | | | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | | FWA |
| 03/07/89 | | | | | | | 1 | | NO | | |
| 03/16/89 | | | | | | | 1 | | NO | | |
| 03/16/89 | | | NO | NO | | | 1 | | NO | | |
| 03/17/89 | | NONE | NO | YES | GULL* | | 1 | | NO | | |
| 03/20/89 | | NONE | NO | | REDTAIL HAWK* | | 1 | 50.0 | YES | | FOU |
| 03/21/89 | | | YES | NO | | | 1 | | NO | | |
| 03/24/89 | | | | | COMMON STARLING | 21275 | 1 | 3.0 | UNK | | |
| 03/24/89 | | | | | HOUSE SPARROW | 70212 | 1 | 1.0 | YES | | |
| 04/02/89 | | | | | GULL* | | 1 | | YES | | LAX |
| 04/07/89 | | ATB | NO | NO | GULL* | | 1 | | YES | | LAX |
| 04/10/89 | | NONE | NO | NO | MOURNING DOVE | 2P105 | 1 | 4.0 | YES | | |
| 04/12/89 | | | | | | | 1 | | NO | | |
| 04/1[illegible]/89 | | NONE | NO | ONE | RING-NECKED PHEASANT | 4L161 | 1 | 40.0 | YES | | LWS |
| 04/2[illegible]/89 | | NONE | | NO | MONGOLIAN PLOVER | 5N45 | 1 | 2.0 | NO | | |
| 04/2[illegible]/89 | | ATB | NO | YES | STARLING | 21275 | 1 | 3.0 | YES | | DAY |

| _02_1 | US_INCID | CTY_PRS | AIRPORT | LOCALE | REMARKS |
|---|---|---|---|---|---|
| | NO | | | VICTORIA, CANADA | DEBRIS IN CORE AND BYPASS |
| | NO | | GIG | RIO DE JANEIRO | FAN EXIT GUIDE VANES BROKEN |
| 40.0 | NO | | | MOUNT GAMBIER, AUSTRALIA | 1ST IMP BLADE BENT, 1ST DIFF VANES BENT |
| 14.0 | YES | | SHV | SHREVEPORT, LA | |
| 4.0 | YES | | ORD | CHICAGO, IL-OHARE | FOUND ON GRD INSPEC |
| | NO | | | CHESTER, ENGLAND | |
| | YES | TX-OK | TX | MONROE, TX | |
| 88.0 | YES | SNA-SMF | SMF | SACRAMENTO, CA | DAMAGE TO 1 STG COMP BLADES |
| 4.0 | YES | | FWA | FORT WAYNE, IN | FOUND ON GRD INSPEC |
| | NO | | | | |
| | NO | | | BUDAPEST, HUNGARY | |
| | NO | | | BRAZIL | FAN BYPASS STATORS EXITED FAN EXHAUST |
| | NO | | | OXFORDSHIRE, ENGLAND | ENG REMOVED TO CLEAN OUT BIRD DEBRIS |
| 50.0 | YES | | POU | WAPPINGER, FL | |
| | NO | | | CARATHA, AUSTRALIA | FOUND ON GRD, 8,1ST STG COMP BLDS BENT |
| 3.0 | UNK | | | | |
| 1.0 | YES | | | | |
| | YES | | LAX | LOS ANGELES, CA | ENGINE CHANGE, AIRCRAFT SA227AC |
| | YES | | LAX | LOS ANGELES, CA | |
| 4.0 | YES | | | DAYTON, OH | |
| | NO | | | BENSON, ENGLAND | FOUND ON GRD INSPEC |
| 40.0 | YES | | LWS | LEWISTON, ID | |
| 2.0 | NO | | | BEIJING-LANZHOU, CHINA | |
| 3.0 | YES | | DAY | VANDALIA, OH | |

# APPENDIX C
## STATISTICAL METHODS USED

Statistical analyses are based on an underlying probabilistic model of the process that gave rise to the data. For example, to provide the basis for comparing the weights of ingested birds in the United States and overseas, it is necessary to hypothesize an underlying random distribution of bird weights. That is, the analyst hypothesizes that there is a population of birds, that these birds have different weights, and that the ingestion process "picked" birds from this population in such a way that all birds had equal chances of being selected (this is really the meaning of "random").

Statistical analyses are somewhat more sophisticated than descriptive data analyses, and more care is required to ensure that the methods are appropriate for the data. Statistical analysis is basically formalized inductive reasoning. Hypotheses about bird ingestion hazards are evaluated for consistency with the data that have been collected. Statistical analysis provides the rules for quantifying the level of consistency between the data and a given hypothesis, and thereby forms the basis for objective and unbiased decisions. The process is known formally as statistical hypothesis testing, and a brief outline of the procedure is presented here.

The basis of a statistical hypothesis test is the hypothesis, which is a formal statement about a relationship in the data. If the data are found to be inconsistent with the hypothesis, then the hypothesis is rejected. Conversely, if the data are consistent with the hypothesis, the hypothesis <u>cannot be rejected</u> and is then tentatively <u>accepted</u>. (Note that a tentatively accepted hypothesis may have to be rejected on the basis of later data; hence, failure to reject is not the same as proof of validity. By contrast, a hypothesis that is rejected is unlikely to be "accepted" on the basis of later data.)

For instance, in comparing the weight distributions of United States ingestions versus foreign ingestions, one hypothesis is that there is no difference in the sizes of the birds ingested in the two regions. However, because of randomness in the ingestion process, it would be very surprising if the data on bird weights were identical for the two regions. The purpose of the statistical analysis, then, is to determine whether the data are consistent with the hypothesis, despite the occurrence of random variation.

The rules for deciding whether to accept or reject the hypothesis are based on the possible errors that could be made. A type I error refers to the situation in which the hypothesis is true but we reject it. A type II error occurs when the hypothesis is false but we fail to reject it (we accept it).

The goal of the statistician is to minimize the likelihood of both types of errors. Unfortunately the likelihood of a type I error is reciprocally linked to the likelihood of a type II error, so that lowering the likelihood of either type of error raises the likelihood of the other type error.

Since only one of the errors can be fully controlled, it has become standard practice to control the likelihood of a type I error and accept whatever probability of a type II error results. The likelihood of a type I error is called the "significance level" of the test. The test hypothesis is chosen so that it should be accepted unless there is strong evidence that it is not true.

If the data appear to present strong evidence that the hypothesis is false, then the hypothesis is rejected. With likelihood equal to the significance level, this rejection is a mistake caused by randomness in the data.

For instance, if we hypothesize that there is no difference in the weight distributions of birds ingested in the United States and overseas, we would then select a statistical test which has a low significance level (such as 1 percent). That is, the probability of falsely rejecting the hypothesis is controlled to be 1 percent. If the test showed the data to be inconsistent with the hypothesis, then we would consider ourselves safe in rejecting the hypothesis.

Another aspect of evaluating the efficiency of a statistical test is its ability to detect when the test hypothesis is false. This ability is called the power of the test and is defined to be the probability of rejecting the test hypothesis when it is false and should be rejected. Generally there are many alternatives to the test hypothesis. For instance, one alternative to the hypothesis of equality of bird weight distributions inside and outside the United States is that birds outside the United States are heavier than those inside. Yet another alternative hypothesis is that birds outside the United States are lighter than those inside the United States. A test which was very powerful under the first hypothesis might be very weak under the second hypothesis. The power of a test is therefore a function of the specific alternative hypothesis being considered.

A variation on the statistical hypothesis test is the calculation of a confidence interval for a parameter such as the overall probability of ingestion (POI). The POI is computed by dividing the number of ingestion events by the number of opportunities for an ingestion event. However, because of randomness, the actual number of ingestions might be more or fewer than the number associated with the "true" POI. Since we have made no specific hypothesis about the POI, we use a confidence interval to describe the range of probabilities which is consistent with the data. The confidence level associated with a confidence interval is the likelihood that the true value of the parameter (in this case the POI) is contained within the interval. The confidence level thus amounts to one minus the significance level of a hypothesis test.

In determining whether the data are consistent with a particular hypothesis, we must sometimes account for "degrees of freedom." Suppose that a population can be described by two parameters. For illustrative purposes we can use the mean and qstandard deviation. Note in particular that the mean is used to compute the standard deviation. Suppose we have a hypothesis that a certain population has specific values for the two parameters. We could test the hypothesis by collecting a sample of, say, 10 items from the population. We would compute the sample mean and use a statistical test to compare this with the hypothesized mean. In addition, we would compute a standard deviation from the sample data, <u>using the hypothesized mean rather than the sample mean in the computation</u>. We would then use a statistical test to compare the computed standard deviation with the hypothesized standard deviation. In both cases, we would reject the hypothesis if the statistical test showed there was "too much" difference between the computed and hypothesized values. In computing the two "statistics," we would have used the 10 independent sample values. The tests would then be said to have 10 degrees of freedom.

Suppose, alternatively, that we have no hypothesis about the mean, but we wish to estimate the standard deviation. We could again collect a sample of 10 items. We would compute the mean from the sample, and use this computed mean in the computation of the standard deviation. In statistical parlance, we have "used up one degree of freedom" by so doing. The standard deviation no longer involves 10 independent items. Once the sample mean is fixed, then only 9 items can be picked independently. The value for the 10th is already determined by the first 9, since it must be such as to produce the fixed mean.

A similar situation arises in chi-square tests. For instance, suppose an overall rate is to be compared with a rate in each of several categories. An instance of this is computing an overall ingestion rate per operation and comparing this with individual engine ingestion rates. Computing the overall rate uses up one degree of freedom, reducing the degrees of freedom available to determine the power of the test in distinguishing genuine differences among the categories.

In general, then, when an estimate of one parameter involves another parameter, which itself must be estimated from the sample, we lose degrees of freedom. The consequence is that the statistical test is less effective. For a given likelihood of a type I error, there is a higher likelihood of a type II error (the test has lower power) than would be the case if more degrees of freedom were available. In all cases in the report where this issue is relevant, the number of degrees of freedom of the statistical test is stated.

In the report, the term "Bernoulli trial" is used. This refers to a situation (trial) in which only two outcomes are possible: heads/tails, success/failure, damage/no damage, etc.



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